POINT TO POINT

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Points of view

SINCE the advent of radio, it has been accepted that the equipment must be able to operate in the environment in which it has found itself. This was not difficult when performance requirements were relatively unsophisticated, because equipment was in any case simple and rugged, and operating tolerances were such that wide variations in ambient temperature and humidity could be tolerated without much difficulty. The effects of dust and insects were regarded as tiresome, and equipment had to be made such that it would tolerate the effects of these without making excessive demands on maintenance personnel. The possibility of using air conditioning was not considered.

Equipment specifications in many cases still call for ability to withstand wide ranges of environmental conditions, even when highly sophisticated performance is called for. This situation also applied, up to perhaps 1950, in the telephone field, but by then it was apparent that, particularly in the case of automatic exchanges with large amounts of electro-mechanical equipment, this policy was costing a lot of money in terms of excessive equipment failure rates and high replacement and maintenance costs. It is interesting to note that this problem was first considered seriously by telephone engineers, as those mainly tropical areas, where the problem is most acute, are generally those which draw heavily on European or American experience for guidance. It is perhaps a measure of the problem that the lead in establishing air conditioning was taken by them as the most economic solution to the problem of providing reliable service in the long term.

It is only much more recently, if yet, that the desirability of using at least a degree of air conditioning for radio equipment rooms has been considered in any detail. Fundamentally, it must always remain a question of economics. The reduction in equipment first cost and subsequent maintenance costs by using air conditioning can be surprisingly great. When these advantages are combined with a shortage of skilled maintenance engineers the case in favour of limiting the range of environmental conditions by air conditioning is very strong indeed. In one particular instance a reduction of approximately 15% of the first cost of an equipment was obtained by reducing the maximum component temperature rating from 75°C to 55°C, and by easing impregnation requirements. While this may be exceptional, it at least illustrates the cost of an additional 15—20°C in upper ambient temperature limit.

In some cases, the required performance cannot be obtained over the full range of temperature and humidity likely to be experienced where the equipment could be installed (or only at prohibitive cost). This is, perhaps, exemplified when highly stable transmitter drives are used, or in microwave equipments where such as cavity or waveguide filters are used to obtain selectivity.

Paradoxically, it will be the cheaper and simpler equipment that will still have to withstand what can be pretty punishing conditions, as it is unrealistic to expect even simple air conditioning on most of the smaller transmitting and receiving stations in which this class of equipment will always be used. A.J.W.

Applications for Ferrite Resonance Isolators

E. F. SCHELISCH, Dipl-Ing

As the capacity of microwave radio relay links increases, so the permissible amount of distortion in the overall system is reduced. An important contribution to this distortion is made by reflections in the RF portions of the link equipment. These can be much reduced by ferrite isolators.

1 INTRODUCTION

FOR A LONG TIME microwave engineers have been looking for a non-reciprocal device which will pass microwave energy only in one direction and absorbs nearly all the energy transmitted in the reverse direction; in other words, a 'one-way street' for microwaves. A microwave circuit component having such properties can be used with great advantage in many ways and some applications will be mentioned in this article.

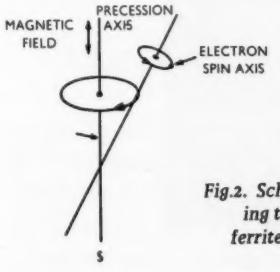
2 PRINCIPLE OF OPERATION

A number of non-reciprocal electro-magnetic effects are known, and amongst these the gyromagnetic properties of ferrites have found widespread application. Ferrites are chemical compositions of the general formula MFe_2O_4, where M represents a divalent metal. These ferrites have been used for many years as magnetic material at low frequencies. When their properties were investigated at higher frequencies it was found that dispersion due to resonance absorption occurred in certain frequency bands, and the resonant frequency of at least one of these bands could be increased by an external magnetic field. A theoretical investigation has revealed that this particular resonance may be due to spinning electrons, and when a spin axis is momentarily displaced, this axis will precess. The frequency of this precession depends on the magnitude of a

magnetic field applied in the direction of the precession axis. A high-frequency field, circularly polarized in a plane perpendicular to the axis of precession, will interact strongly with this precession when the precession frequency and the frequency of the electro-magnetic field are approximately equal. (See Fig.1.) A non-reciprocal effect is observed when the direction of circular polarization changes.

High-frequency electro-magnetic fields with circular polarization can easily be produced, or are present, for example, in rectangular waveguides. The field on either side of the E-plane centre line has a strong component of circular polarization. The direction of polarization depends on the direction of propagation and the side being considered. When a piece of a suitable ferrite is inserted into a waveguide on one side of the E-plane centre line and an external magnetic field of suitable strength is applied to the ferrite, parallel to the E-vector, it will be found that the absorption is different for each direction of propagation. The magnetic field theoretically required is approximately 320 Oersted per 1 000 Mc/s (this figure is different in practice due to demagnetization effects in the ferrite, the chemical composition of the ferrite and several other factors). The ratio of attenuation in each direction depends on the shape of the ferrite, the field configuration in the waveguide with the ferrite present, etc, and this ratio can be improved by the insertion of additional dielectric material into the waveguide. The usual arrangement is shown in Fig.2. The relative values of attenuation in dB are

Fig.1. Electron precession



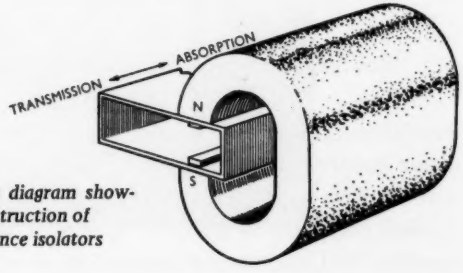


Fig.2. Schematic diagram showing the construction of ferrite resonance isolators

approximately proportional to the length of the ferrite in the direction of propagation. The bandwidth over which a reasonable ratio can be maintained is mainly determined by the non-uniformities in the ferrite material and the magnetic field (normally supplied by a permanent magnet). The temperature range for such a resonant ferrite device depends on the Curie temperature of the ferrite and other effects, but this range can be greatly increased by a suitable cross-sectional shape of the ferrite slab.

3 TYPICAL EXAMPLES

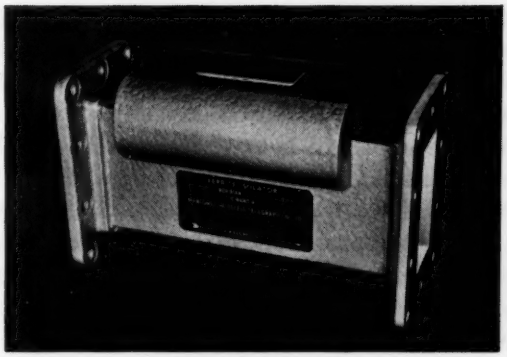
Although other effects such as Faraday rotation in ferrites can be employed to produce a non-reciprocal attenuation in transmission lines, the principle of resonance absorption in ferrite has much to commend it. This principle leads to a very simple and economical design of great rigidity and electrical stability. Ferrite isolators for the lower part of the microwave frequency spectrum are extremely difficult to make but are a practical proposition in frequency ranges above 2 000 Mc/s.

For most applications an isolation of the order of 20 dB is sufficient. This has to be obtained in conjunction with a reasonably low forward loss and this can be kept below 1 dB at the lower frequencies and below 0·5 dB at the higher frequencies. (These figures normally apply to a bandwidth of 10%.) In other words, isolation ratios of 20:1 (at 2 000 Mc/s) and 40:1 (at 10 000 Mc/s) with a bandwidth of 10% can be economically produced. This is, of course, the ratio at the edges of the band, and is higher in the centre. In certain cases where only a narrow band is required, this ratio can be increased to 80:1 or even 100:1.

4 FIELDS OF APPLICATIONS FOR FERRITE ISOLATORS

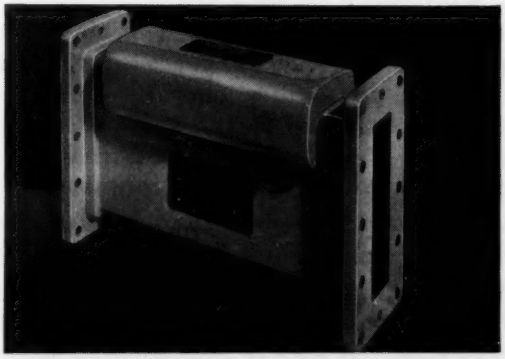
4.1 FOR LABORATORY MEASUREMENTS

Ferrite isolators serve a very useful purpose in the isolation of microwave generators from reflected waves occurring in an unmatched load circuit. This is particularly important when the frequency of an uncontrolled oscillator is affected by load changes (e.g, when a klystron is used to feed microwave energy into a system under test, the frequency



Typical 'S' Band ferrite isolator

will normally not remain constant during the test, or alternatively, it may become severely unstable at certain values of load impedance). In order to overcome this difficulty it was customary to insert an attenuator into the waveguide between the klystron and the circuits connected to it. The loss had to be at least 10 dB, so that the reflected waves could not seriously affect the loading conditions of the klystron. This attenuator



Typical ferrite isolator for use in 2000 M/cs band

obviously reduced the energy fed into the associated circuits, and thus reduced the range of level variation, standing wave ratio, etc, which can be measured, because the upper limit of the measurements is given by the available power, and the lower limit is determined by the sensitivity of the measuring instruments or by a given noise level. Filter measurements, in which considerable reactance variations in the circuits are inevitable, have always been troublesome. The use of an isolator helps here by providing a wideband protection against these unwanted reflections, and increases the amount of power available for the tests by at least 10 dB.

Furthermore, isolators can be used for the correct termination of circuits such as directional couplers, hybrids, etc., which need matched load conditions at their terminals for proper operation.

The number of possible ways in which isolators may be used is, of course, almost unlimited. But a further case may be mentioned in connection with a modern type of amplifier, the MASER (Microwave Amplifier with Stimulated Emission of Radiation). In many designs of such amplifiers, the input signal and the output signal appear at the same port. An isolator can be used to prevent the amplified signal from travelling towards the signal source, without introducing a large attenuation for the incident signal. (It may be mentioned that a better solution for this problem is the use of a 'circulator', which is a microwave circuit element also employing a ferrite. (In this case the ferrite is used for the purpose of producing a non-reciprocal phase shift.) Energy fed into one of several ports will leave the network at only one other port.)

4.2 IN COMMUNICATION EQUIPMENT

The great technical and economic value of ferrite isolators becomes apparent in their use in microwave communication equipment, particularly in wideband multichannel equipment. In explanation, one of the main sources of distortion in such equipment may be mentioned briefly.

The most important type of wideband multichannel telephone link employs frequency modulation for the microwave carrier. Frequency

modulated signals are affected to only a limited degree by amplitude variations in the transmission path, and by amplifier non-linearity. However, they are affected adversely by group-delay variations, or by the recombination of signals which have suffered different delays in propagation. This latter effect is observed in long aerial feeders; the transmitted signal may be reflected at the aerial end of the feeder due to a slight mismatch, and the reflected signal travels back to the transmitter end and, is again reflected, at much reduced level. During the time taken to traverse the feeder to the aerial and back, the instantaneous frequency of the transmitter has changed. The resulting combination leads to distortion of the microwave signal and consequently of the multichannel baseband signal after demodulation, and produces crosstalk. The number of channels which can be transmitted with a specified performance can be seriously limited by this crosstalk, and extreme care is required to reduce it to acceptable levels during the installation of aerials and feeders. A voltage standing wave ratio of less than 1·05, or 1·02, is desirable for 240, or 600 channel systems, but can be extremely expensive to achieve and very difficult to maintain by conventional means. This is a case where isolators show to great advantage, as they reduce the costs for new installations and permit the improvement of existing ones. By installing isolators, the channel capacity of existing microwave equipment can frequently be increased.

Connections between microwave amplifier stages can cause distortion when using filters, and the insertion of isolators can also be useful in this case.

Yet another circuit in radio link equipments where isolators are successfully used is the mixer. Mixers contain non-linear elements which not only produce the desired intermediate frequency, but also harmonic frequencies of the received signals and the local oscillator frequency, together with combination frequencies. Several of these combination frequencies can fall into the frequency range of the received signal, and these can be the cause of serious distortion when reflected by an input filter. Consequently, an isolator can, with advantage, be inserted immediately in front of mixers.

5 CONCLUSION

These selected examples show that ferrite isolators fill a real need. The possible field of application is much greater when specialized microwave circuits and also military applications are taken into consideration. However, even ignoring possible military applications, isolators of this type justify the considerable amount of research work which has been involved, since the use of a simple and relatively inexpensive device permits radical simplification of the design of high capacity radio relay systems.

E. F. SCHELISCH, born at Frankfurt/Main, Germany, in 1916 and educated at Moeller-van-den-Bruck Schule, Solingen, Germany. He completed his academic education at the Technische Hochschule Berlin-Charlottenburg, and the Badische Technische Hochschule 'Fridericiana' at Karlsruhe in 1944 as a Diplom-Ingenieur in Mechanical and Electrical Engineering. Until the end of the war he was engaged in the development of DF techniques for guided missiles, and immediately after this he joined the PPT-Branch of the Control Commission for Germany (British Element) where his activities included technical consultation during the rehabilitation of telephone and teleprinter networks, both manual and automatic. In 1949 he came to England and joined the Research Laboratories of the Marconi Company where he has specialized in microwave equipment for communications.

In 1958 he was appointed Deputy Chief of the Research Group which undertakes the development of specialized microwave components.

Equatorial Sunset Effect

A. M. HUMBY, M.I.E.E*

Mr Humby is well known as an expert on propagation effects. That which he describes will be of interest to many communication engineers, and his article, which was originally published in 'Wireless World', July/August 1959, is reprinted by kind permission of the Editor.

IN AUGUST 1947, a year of high solar activity (Fig.1), the writer observed at Singapore that teleprinter operation of the Admiralty circuit to London became extremely difficult, if not impossible, from about 1900 to 2100 local time Singapore (i.e, 1200 to 1400 GMT), a condition which the operating personnel (often only too ready to blame the man at the *other* end) referred to, in those days, as the 'Whitehall Lunch-time Effect'!

The circuit had been equipped with suitably directive aerials at each terminal for operation on a number of frequencies between 4 Mc/s and 22 Mc/s, according to the time of day, season and epoch of the 11-year solar cycle.

For distances exceeding 4 000 km, propagation takes place by a number of complex modes, and it has been found empirically that, for a given frequency, propagation via the F_2-layer is usually practicable so long as

Fig.1. Mean Zurich sunspot numbers for the years 1946 to 1958 inclusive

* Royal Naval Scientific Service

the ionosphere at 'control points', distant 2 000 km from each terminal (Fig.2), supports transmission at that frequency irrespective of the condition of the ionosphere elsewhere along the great-circle path. If this condition is not satisfied at each 'control point' a change to a lower frequency is usually necessary.

In certain cases E-layer propagation may be possible, the investigation of which involves two additional 'control points' distant 1 000 km from each terminal.

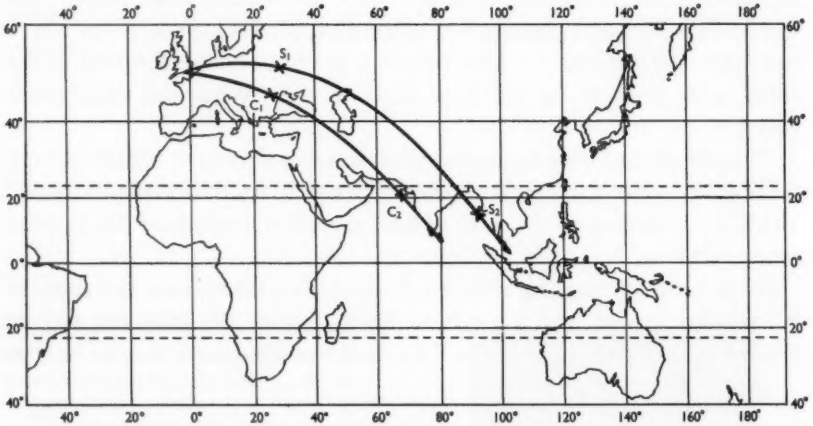


Fig.2. The 'control points' mentioned in the text; S_1 S_2 on Singapore/London and C_1 C_2 on Colombo/London great-circle paths respectively

The extent to which the frequency may be lowered depends upon such factors as the effective radiated power of the transmitter, absorption of signal, and the level of atmospherics and the type of aerial at the receiving terminal. The condition of the ionosphere at any given location is assessed from regular ionosphere soundings carried out at a large number of measuring stations throughout the world, and from this data groups of charts are prepared on a month-to-month basis representing world-wide variations of ionization with the time of day, season and solar activity.

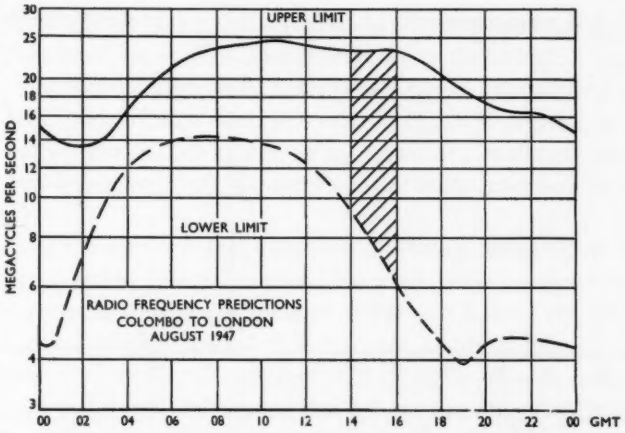


Fig.3. Upper and lower predicted frequency limits for radio-teleprinter operation between Singapore and London, August 1947

Considerable success is now being achieved by ionospheric forecasters in determining the most probable upper- and lower-frequency limits in any given case, and fortunately for the radio engineer, discrepancies between prediction and practice are gradually being eliminated.

Predictions of the type referred to above for the case of the Singapore/London circuit for August 1947 are shown in Fig.3, from which it would appear that a wide band of frequencies should have been suitable for teleprinter operation between 1200 and 1400 GMT; in point of fact although communication on several frequencies within the predicted limits was attempted, this period, as stated earlier, was one which proved in practice to be one of extreme difficulty.

The period 1900 to 2100 local time Singapore (i.e, shortly after sunset) was characterized by:

(a) A reduction of signal intensity in each direction of the Singapore/London circuit.

(b) Excessive multipath distortion arising from the reception of a number of echo signals arriving over different radio paths with sufficiently large time delays to prohibit operation of the circuit at normal teleprinter speed (50 bauds).

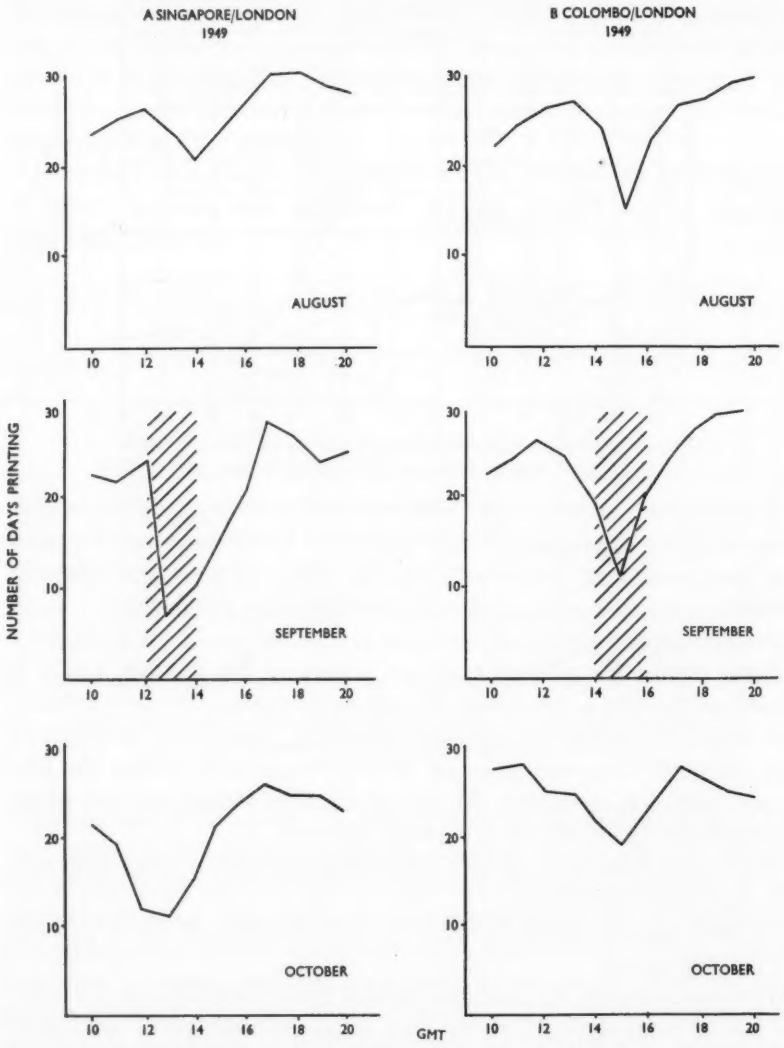


Fig.4. Communication conditions on Singapore/London and Colombo/London radio circuits near local sunset (equatorial region) for equinox months of 1949

However, on many days the signal-to-noise ratio was adequate to permit Morse operation at slow speeds (e.g., 15 to 20 bauds), where, on account of the much longer time intervals between transmitted signal elements, multipath effects were less troublesome. Reception in these cases was carried out either by ear, or by undulator recorder, methods which in themselves are less sensitive than the teleprinter one to multipath distortion.

(c) Direction of arrival of incoming signals being diffused, or 'flat', suggesting considerable azimuthal scattering of the received energy.

With the introduction in the autumn of 1949 of hourly circuit-merit figures indicative of the diurnal performance of all Admiralty radio-teleprinter circuits, it became apparent that a similar, though somewhat less pronounced, difficult period was also being experienced daily on the Colombo/London circuit from about 1900 to 2100 local time Colombo (i.e, 1400 to 1600 GMT).

Figures 4a and 4b show the deterioration in performance of these two circuits near local sunset at Singapore and Colombo respectively for the months of August, September and October 1949.

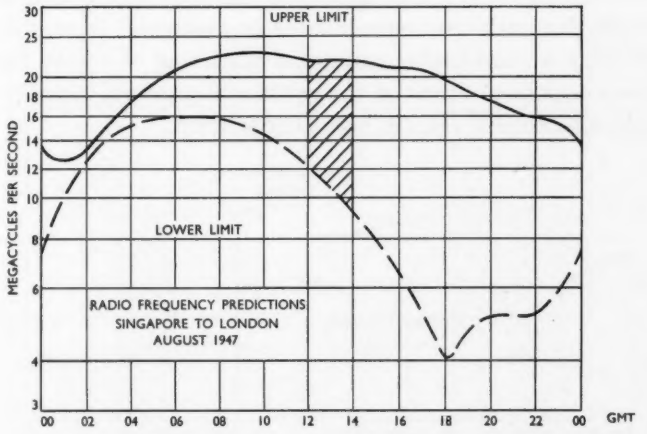


Fig.5. Upper and lower predicted frequency limits for radio-teleprinter operation between Colombo and London during August 1949

As in the case of the Singapore/London circuit, frequency predictions for the Colombo/London circuit based on the 'two control-point' method (C_1 and C_2 of Fig.2) indicated that a reliable teleprinter circuit should have been practicable during the above period of the day (Fig.5).

Further investigation disclosed that the above difficulty on each circuit was essentially a condition peculiar to the equinox as distinct from the solstice. Let us compare, for example, the performance of the Singapore/London circuit for the six equinox months (Fig.6a), with that for the six solstice months (Fig.6b), of the twelve-month period August 1949 to July 1950, inclusive.

The continuation of such records throughout the period 1949 to 1958 inclusive has provided confirmation that the effect under discussion was substantially non-existent in solstice months.

The performance of the Singapore/London and Colombo/London circuits for equinox months are compared in Fig.7 for each year commencing 1949 and ending 1958, and it will be seen, by reference to the annual solar indices shown in Fig.1, that the equatorial-sunset effect under discussion was associated with years of high solar activity.

To summarize. The effects described above relate to difficulties of communication with terminals situated in equatorial areas, the salient feature being a considerable azimuthal scattering of signals for about two hours near local sunset at the equatorial terminal, notably during the equinox months of years of high solar activity.

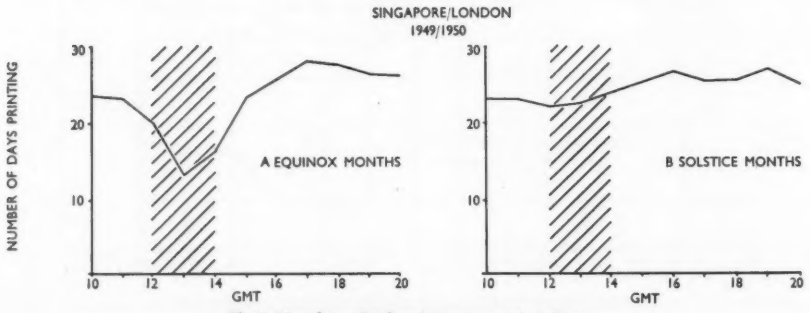


Fig.6. Number of teleprinter operating days on Singapore/London radio circuit for equinox and solstice months of 1949/1950

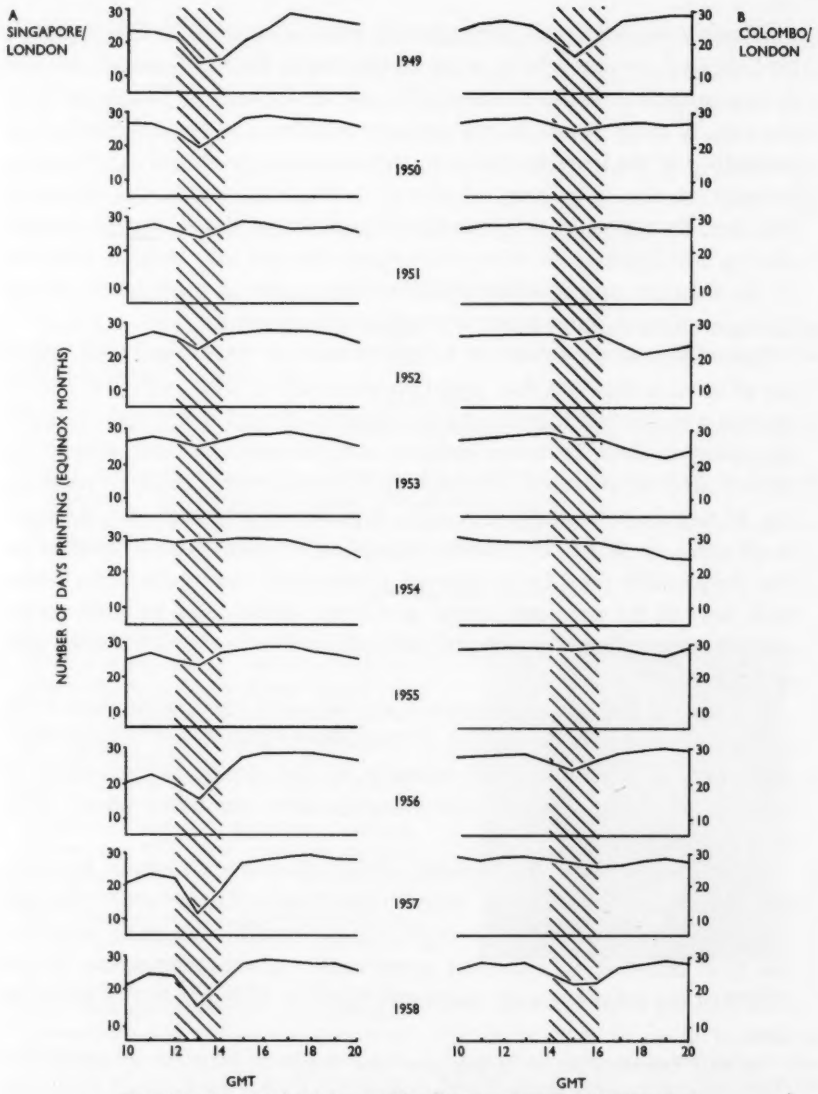


Fig.7. Number of teleprinter working days on Singapore/London and Colombo/London circuits during equinox months from 1949 to 1958 inclusive

Directly related to this phenomenon would appear to be that reported by Osborne[1], as part of the work of the Radio Research Board. He has drawn attention to the disintegration of the F_2 layer at Singapore near the time of local sunset during equinox months, and has referred to the possibility of the frequency of occurrence of this equatorial scatter being greatest at the maximum of the 11-year solar cycle. The effect in practice, he states, is that reflected signals from the F_2 region are not always intelligible, even though the signal strength may be high, whereas at the solstices propagation conditions are better at these hours, when the layer often remains intact throughout the evening.

Some light on the extent to which circuits to other equatorial points are affected in this way has been thrown by Hitchcock[2], who has drawn attention to the fact that during the autumn of 1956 many radio circuits operating in low latitudes suffered severe propagational difficulties shortly after local sunset. This took the form of severe fading, or weakening, of signals sufficiently serious to degrade, or interrupt, the services. In all cases, he states, the normal operating frequency, and the alternative frequencies used in an attempt to maintain communication, were well clear of the predicted upper and lower limits. And he adds, moreover, that the effect was not generally noticeable on circuits during sunspot minimum years.

In view of the apparent correlation between the circuit data from various sources and the results of ionospheric soundings, it is possible that there is a fundamental obstacle to the sky-wave operation of tropical, or partly tropical, circuits under the conditions which have been referred to.

Since the last war, the number of high-frequency circuits has considerably increased, and the period 1947 (high solar activity) through 1954 (low solar activity) to 1958 (exceptionally high solar activity) has thus afforded an excellent opportunity of studying many of the effects of the solar cycle on communication by ionospherically reflected rays.

In this connection it is perhaps not without interest to recall the following statement made by Appleton in 1947[3]: 'Sir Edward Appleton

(in reply): I strongly support Dr Smith-Rose's plea for continued, and indeed extended, post mortem examination of operational results. Only in this way is it possible to check the accuracy of our ionospheric predictions. Moreover, nature has many surprises for us in work of this kind, and, with a laboratory as large as the earth itself, it is only with the co-operation of an army of radio operators that we can ensure that many interesting abnormalities do not escape attention.'

Acknowledgements

The author wishes to thank Miss S. S. Aucken and B. W. Smith, of the Royal Naval Scientific Service, for their assistance in the presentation of the data in this article, which is published by permission of the Admiralty.

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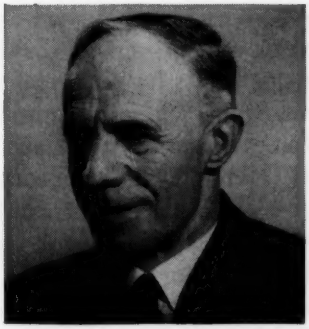
3 Discussion on 'The Investigation and Forecasting of Ionospheric Conditions', by Sir Edward Appleton; *Journal I.E.E*, 1947. Vol. 94, Part IIIA, p. 878.



A. M. HUMBY, born 1896, was educated at Christ's Hospital and served as Battalion Signals Officer in the first World War. In 1919 he spent a year as a Radio Operator with the Marconi Marine Company and in 1920 joined the engineering staff of M.W.T Co.

When Cable & Wireless was formed in 1928, Mr Humby transferred as Manager and Engineer-in-Chief of the Bridgwater Receiving Station. For four years from 1934 he was engaged in research and development at Electra House. In 1941 he was seconded to the Admiralty and subsequently joined the Royal Navy Scientific Service. In 1951 he was again seconded, this time to the British Joint Communications Electronics Board and has since been appointed to the Joint Communications-Electronics Staff of the Ministry of Defence. Included in his duties is the Chairmanship of the N.A.T.O Study Group on Ionospheric Scatter and membership for the U.K of the Study Group on Tropospheric Scatter. Mr Humby, who is well known in the field of propagation, is also a member of the National Committee of the C.C.I.R.

A Comparison between Alternative HF Telegraph Systems

J. V. BEARD, B.Sc.(Eng.), A.M.I.E.E, and
A. J. WHEELDON, M.A, A.M.I.E.E

Many claims are made for the various systems that may be used for the transmission of telegraphy over HF radio links. This article attempts an objective review of the alternatives in terms of the 'ideal detector'.

1 INTRODUCTION

OVER THE YEARS, numerous types of telegraph systems, employing a variety of modulation methods, have been developed in an endeavour to obtain improved performance. The performance of HF telegraph systems has been exceedingly good for many years, so much so that any new attempt at improvement could be negatived in comparison with existing systems unless its performance, at all points, is at an extremely high level. Under these circumstances, an absolute basis of comparison becomes essential. Until recently, the only basis was by comparative trial (preferably simultaneously, using the same aerial, frequency and route), as no absolute standard of reference existed. If different types of modulation were used or the systems being compared were designed for different keying speeds, then the results were difficult to assess, and could be inconclusive or misleading.

In the main, two alternative methods of comparison were used, based on telegraph distortion. The outputs from the systems under test were examined by a short element fault counter; this recorded the number of elements for which distortion exceeded a given amount. Over the range of conditions met in practice, this method of test can lead to the wrong

conclusion, since a wide-band system always gives lower distortion levels at high signal/noise ratios, when compared with a narrow-band system. Conversely it can be seen from Fig.1 that the narrow-band system is superior on low signal/noise ratios. An alternative method is to count the errors on a printed test transmission. This is very tedious to analyse and involves the margins of electro-mechanical printers (unless a regenerator can be used). Moreover, the printers will normally only operate at one speed, while it is often necessary to find the keying speed at which the system gives the optimum performance.

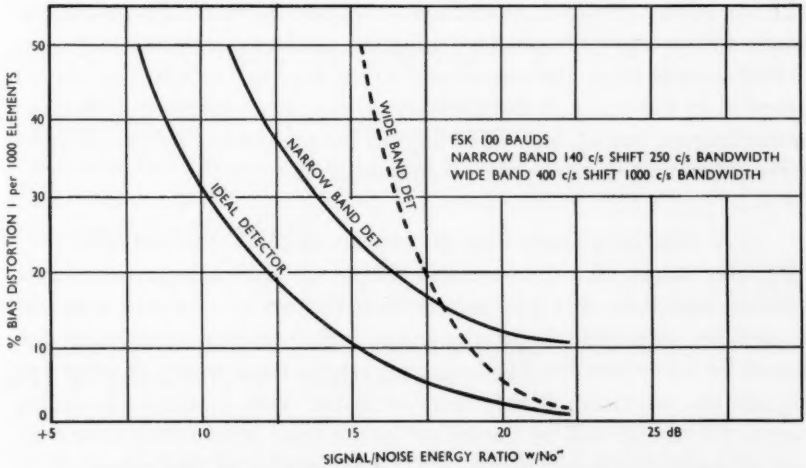


Fig.1. Bias distortion on an FSK system narrow-band VS wide-band detectors

The concept of the 'ideal detector', that which would give the lowest error rate theoretically possible for any given signal/noise ratio, gives the desired absolute basis of comparison. This concept, as is well known, was introduced by H. B. Law in 1957.[1] Much experimental evidence, both from the laboratory and from traffic trials, has been amassed since

that time, but it has to a large extent been limited to AM and FM systems, and has been directed more to the derivation of the nearest practical approach to the ideal than to comparing the merits of existing systems under practical conditions. The engineer in the field could be excused for feeling uncertain, in the light of rival claims, as to the relative merits of the available alternatives. This article attempts a comparison, in the light of published information, based on error rates, in terms of received signal/noise ratio and bandwidth efficiency, with particular emphasis on the effect of the propagating medium.

2 THE 'IDEAL DETECTOR'

The aim of any telegraph system is to transmit the maximum amount of traffic within a given bandwidth using the minimum transmitter power, taking account of the limitations of the propagating medium. The critical element in the chain is the receiver, which is required to detect the wanted signal (which may be fading) in the presence of noise and interference from other unwanted transmissions.

2.1 PERFORMANCE UNDER STEADY SIGNAL CONDITIONS

The later stages of a conventional frequency shift telegraph receiver consists essentially of a final intermediate-frequency amplifier, a limiter to remove amplitude fluctuations, and a frequency discriminator followed by a low-pass filter and squaring stages, from which dc telegraph signals are produced. If this receiver is fed with a noisy, non-fading signal, the limiter will be 'captured' by the noise whenever a noise peak instantaneously exceeds the signal. The probability of this occurring, P_e, is given by the Rayleigh formula

$$P_e = \exp\left(-\frac{S}{N}\right)$$

where S is the signal power and N is the noise power.

In a conventional receiver, the discriminator characteristic is anti-symmetrical about the crossover point midway between the mark and space frequencies, and the selectivity curve is symmetrical about this point. Thus under non-fading conditions, there is an even chance that a

noise peak will change the sign of the discriminator output, and cause an error to be printed. The overall probability of element error P_e therefore becomes:

$$P_e = \tfrac{1}{2}\exp\left(-\frac{S}{N}\right) \tag{1}$$

In the assessment of practical systems, the bandwidths and telegraph keying speeds will differ. This can be overcome by taking the energy in a single element and the noise power per unit bandwidth. This ratio is known as the signal/noise energy ratio.

Equation (1) may be re-written:

$$P_e = \tfrac{1}{2}\exp\left(-\frac{w}{N_o}\right) \tag{2}$$

where $\dfrac{w}{N_o}$ = signal/noise energy ratio

$$= \frac{\text{signal power}}{\text{telegraph speed in bauds}} \div \frac{\text{noise power}}{\text{receiver bandwidth}}$$

In a practical system, the error rate will be worse than that of the 'ideal' detector given by equation (2). In general it will worsen by a factor b so that we now have:

$$P_e = \tfrac{1}{2}\exp\left(-\frac{w}{bN_o}\right) \tag{3}$$

The factor b is called the 'demodulation factor' and indicates by how much the practical system falls short of the 'ideal'.

2.2 PERFORMANCE UNDER FADING SIGNAL CONDITIONS

It has been found that fading on a high frequency radio link closely follows the Rayleigh distribution. It has been calculated[1] that in the case of single path reception, the element error rate is given by the formula:

$$P_e = \frac{1}{2\left(1+\dfrac{w_o}{bN_o}\right)} \tag{4}$$

where w_o is the mean signal energy per element.

The factor b in the above equation is again the demodulation factor and has the same significance as in the non-fading case. If a receiver has

been designed correctly, the factor b should be the same in both the fading and non-fading cases.

In the case of double diversity reception the element error rate is given by:

$$P_e = \frac{1}{\left(1+\frac{W_o}{bN_o}\right)\left(2+\frac{W_o}{bN_o}\right)} \qquad (5)$$

The factor b has again the same significance as before. If b is worse under these conditions, it indicates a deficiency in the path combination or selection circuits.

2.3 EXPERIMENTAL ASSESSMENT OF DEMODULATION FACTOR

By suitably simulating a fading HF circuit, and the effect of noise at the receiving site, a receiver may be tested under controlled conditions. (The result will reflect the extent to which the fading and noise resembles those experienced over a practical circuit.) Such a 'fading machine' has been constructed at the G.P.O Research Station at Dollis Hill. A block schematic of the test apparatus is shown in Fig.2.

An LF oscillator running at the desired keying speed keys a telegraph signal generator to produce either reversals or a random telegraph signal (the latter is produced by regenerating random LF noise at a speed determined by the oscillator). The output of the telegraph signal generator keys a low power transmitter drive which is capable of producing the

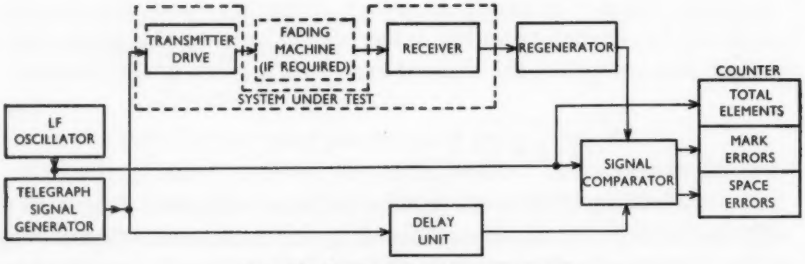


Fig.2. Block schematic of test apparatus

desired modulation. The signal is then passed to the receiver via an attenuator (for non-fading tests) or via the fading machine (if Rayleigh fading is required). The signal/noise ratio may be conveniently varied by injecting white noise into the receiver input.

The telegraph output from the receiver is regenerated by inspection pulses which are derived from the LF oscillator. The phase of these is adjusted to coincide with the middle of the received telegraph elements, so that nearly 50% distortion in the receiver output can be tolerated before an error is produced. The regenerated signal is compared element by element with the delayed original signal. The mark and space errors are counted electronically, and a plot is made of signal/noise ratio versus error rate, and the results compared with the ideal detector.

This arrangement tests under synchronous conditions. So long as element error rate is being assessed, the results are, of course, identical for start/stop and synchronous conditions, but if character error rates are the basis of comparison, the two systems give substantially different results. The following table is taken from C.C.I.R report No. 105 (Los Angeles 1959) and shows the character error rate expressed as a multiple of the element error rate for different types of operation.

TABLE I

Code	*Character error rate (multiple of element error rate)*
5-unit synchronous	$5\,P_e$
7-unit synchronous	$7\,P_e$
5-unit start/stop (tape printer)	$17\,P_e$
5-unit start/stop (page printer)	$34\,P_e$

2.4 RECEIVER CHARACTERISTICS AFFECTING DEMODULATION FACTOR

It will have been noticed that the criterion established by the concept of the ideal detector is that of signal/noise energy ratio *at the detector*. Apart from the rejection of unwanted transmissions, the influence of the

earlier stages of the receiver is limited entirely to their effect on this ratio. The factors which must be considered are as follows:

Pre-detector bandwidth
Receiver gain
Receiver noise factor.

These are considered below.

2.4.1 *Pre-detector bandwidth*

The optimum pre-detector bandwidth is that which is sufficient to admit only the significant signal components of the telegraph transmission. This depends on the keying speed and (in the case of Frequency Shift systems) the modulation index. Excess bandwidth at this point will admit unnecessary noise to the detector, and reduce the signal/noise energy ratio, thus degrading the output of the receiver.

It has been suggested[2] that this demodulation factor penalty can be expressed by a factor E

$$E = 10 \log \frac{F}{2B} \quad \text{(for FSK transmissions } M > 2\text{)}$$

$$E = 10 \log \frac{F}{B} \quad \text{(for other systems and FSK transmissions where } M < 2\text{)}$$

where:

F = pre-detector bandwidth at -3dB points

B = telegraph keying speed in bauds.

If, however, the filter bandwidth is such that significant sidebands of the transmission are excluded, then the signal/noise ratio at the detector will be reduced. This reduction can be expressed as:

$$R = 20 \log\left(\frac{2D+B}{F}\right)^{*}$$

* In the case of FSK transmission.

where $2D$ is the frequency shift in c/s.

R only has significance if $(2D+B) > F$, as for values less than unity there is no reduction in signal power.

The total degradation due to the effect of pre-detector bandwidth is $R+E$ dB.

Excess pre-detector bandwidth may arise from the need to obtain a suitable filter phase response, or to cater for poor frequency stabilities at transmitter or receiver (or inadequate AFC performance).

2.4.2 *Receiver gain*

Since the provision of receiver gain is costly, and can increase potential unreliability, the gain should be the minimum consistent with detector requirements. To this, must be added a sufficient margin for ageing and a degree of misadjustment. This minimum gain can be determined as that required to load the detector fully on atmospheric noise when connected to an aerial at the quietest site from the point of view of both man-made and atmospheric noise.

The level of noise pick-up will be dependent on the aperture of the aerial and, if the noise at the receiver site is directional, also on the polar diagram. In general, use of a directional aerial will result in an increase in the wanted signal compared with a dipole or elementary aerial, and since noise is usually directional, some reduction in noise level will also result if the wanted signal is coming from a quiet part of the world.

A study of charts produced by the C.C.I.R on noise levels[3] indicates that the lowest noise signals induced are as set out in Table II. (The noise is expressed in dB relative to thermal noise in 75 ohms at room

TABLE II

Frequency	*Man-made noise*	*Galactic noise*	*Atmospheric noise*	*Total noise for omni-directional aerial (approx.)*	*Min. total noise for directional aerial at a quiet site*	*Min. Rx. noise factor required (dB)*
3 Mc/s	+40	+40	+13	+43	+25	20
10 Mc/s	+25	+30	+25	+30	+18	13
20 Mc/s	+18	+22	+10	+25	+15	10
25 Mc/s	+15	+20	+7	+22	+12	8
30 Mc/s	+10	+18	+5	+20	+10	6

temperature.) This is borne out by tests on quiet sites in the U.K in April, when atmospheric noise is at a low level.

The receiver gain need only be sufficient to load the detector fully for a noise input of this amount, apart from any desired operational margin.

2.4.3 *Noise factor*

The noise factor of the receiver must be such that under operational conditions, the contribution of noise from the receiver input circuits is approximately 4—6 dB below the minimum noise induced in the aerial from all sources. This allows adequate margin for degradation in operation without decreasing significantly the fundamental signal/noise ratio at the detector.

This concept leads to the conclusion that there is no merit in obtaining a noise factor lower than the values given in Table II for communications receivers in the HF band. These figures are conservative and include feeder loss of 3 dB. They are, of course, somewhat inferior to those currently sought, and it is interesting to note that it is only in the case of frequencies above about 40 Mc/s, where atmospheric noise is substantially lower, that it is necessary to strive to achieve the lowest possible noise factor. (In a practical case, a noise input level at the aerial terminals of +6 dB at a frequency of 37·5 Mc/s was recorded at a very quiet site.)

3 COMPARISON OF PRACTICAL SYSTEMS

The three basic types of modulation, by amplitude, frequency and phase, can be used for the transmission of telegraph information. Practical systems exist using each of these.

3.1 AMPLITUDE MODULATION

3.1.1 *The ON/OFF System*

An ideal ON/OFF detector should have a bandwidth of only B c/s (B=telegraph speed in bauds). Since, on the average, it is only receiving energy half the time, it will have a 3 dB penalty compared with a constant-power system. Thus we should expect a perfect ON/OFF detector to have a demodulation factor of 3 dB. Although this result can be

obtained in the laboratory, practical receivers possess demodulation factors substantially in excess of this theoretical minimum, for a variety of reasons which are discussed below.

The most popular detector in both past and current practice is of the 'slide back' type, which detects the signal at half amplitude. This arrangement is the most effective for dealing with fading signals.

Fig.3 shows the circuit in its simplest form. The signal at IF or LF is applied to a transformer which has a 2:1 tap on its secondary winding. The larger voltage is rectified by the diode $D1$, and produces negative going pulses of approximately $E\sqrt{2}$ across $R1$. Since the time constant $R1C1$ is short, the detected waveform across $R1$ follows the signal modulation. The time constant $R2C2$ is long compared with a signal element but short compared with the quasi-fading period; thus the voltage across $R2$ does not follow the signal modulation, but does follow the amplitude changes resulting from fading. Since the voltage across $R1$ and $R2$ add algebraically the output waveform will be symmetrical with respect to earth regardless of the signal amplitude (see Fig.4). The output from the detector is limited, fed through a low-pass filter to remove noise components which are above the highest keying frequency, and again limited in the usual manner.

Receivers in the past have used IF bandwidths of 0·5 to 1 Kc/s. Diversity path combination was very simply carried out by having a

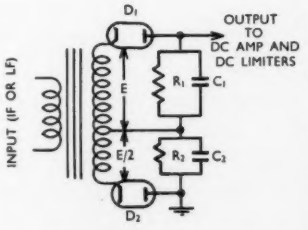


Fig.3. Slideback detector for AM system

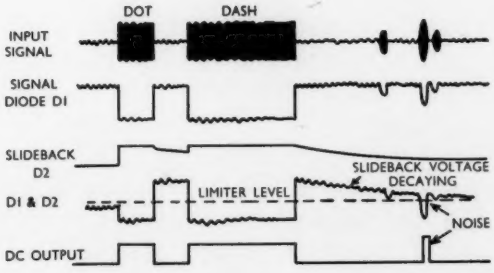


Fig.4. Slideback detector waveforms

common detector load resistor. Such receivers possess a number of advantages, including:

(a) Simplicity in circuitry. Diversity combination by the use of a common diode resistor is very much simpler and cheaper than path selectors or ratio-squaring circuits (which are essential for FSK reception).

(b) The use of a comparatively wide bandwidth enables a simple and cheap AFC system to be used. (This, however, results in a demodulation factor as high as 15—20 dB.)

(c) Since the mark-space decisions are made at half amplitude, 'overshoot' due to poor phase response in the IF filter is far less important than in an FM system. Fig.5 illustrates this point.

The ON/OFF system has several serious disadvantages. Since no signal

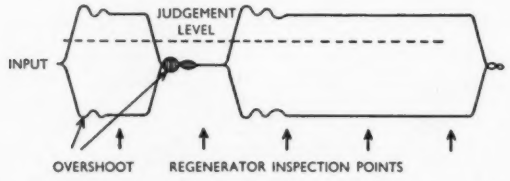


Fig.5. Effect of poor filter response in conjunction with slideback detector

is received during a long space signal, the charge on the slide-back capacitor leaks away, thus bringing the threshold of the receiver nearer to the noise level (see Fig.4). This necessitates accurate adjustment of the gain of each diversity path by the operator, so that the threshold of the detectors is just above the noise level. Too low a level of gain involves loss of usable signals, while too high a level, will increase the noise level at the detector, therefore increasing the error rate on traffic. Since the amplitude of the noise fluctuates in a random manner this adjustment can, at best, be only approximate. This suggests that even for an optimum system in the hands of skilled operators, a demodulation factor of better than about 10 dB is unlikely to be maintained over a period.

3.1.2 *The Two-tone System*

The earliest alternative to ON/OFF modulation was frequency shift keying, discussed in detail in Section 3.2. This has many merits but is susceptible to selective fading and as long ago as 1938 it was felt, by engineers of Cable and Wireless Ltd., that this very shortcoming of the HF medium could be turned to advantage by using a 'double ON/OFF' system, with separate tones keyed in anti-phase for the two signalling conditions. The full telegraph information is, of course, contained in a single tone, and by choosing tones separated by an amount equal to $\frac{1}{2 \times \Delta T}$ (where ΔT = path time delay) then one signal would be at a maximum when the other was most affected by fading[4]. The original experiments did not realize the expected advantage, and the modified landline equipment now in widespread use fails to utilize this fundamental feature of a two-tone system, and it remained for Law and his associates[5] to reinvestigate the situation anew.

Law showed that the optimum use of frequency diversity effectively doubled the number of diversity paths. In other words a double diversity two-tone system gives an error rate curve which lies parallel to a quadruple diversity system. Fig.6 illustrates this point. It shows that the error rate drops from 1 per 1 000 elements for flat fading, where no frequency diversity advantage exists, to 6 per 100 000 elements when the fading is selective (i.e, an improvement of 6·5 dB at an error rate of 6 in 100 000).

Two-tone telegraphy is a constant power system and this gives a 3 dB improvement in signal energy over the ON/OFF case. However, two filters are necessary, one for each of the mark and space frequencies, giving rise to an additional 3 dB of noise power. The theoretical demodulation factor is therefore 3 dB inferior to the 'ideal'. Practical receivers have been designed with demodulation factors of 3—3·5 dB (i.e, very close to the ideal) for the single channel case, and 4—4·5 dB for multichannel systems.

In theory, and probably also in practice, the demodulation factor obtainable with a two-tone system is slightly inferior to that of an FSK

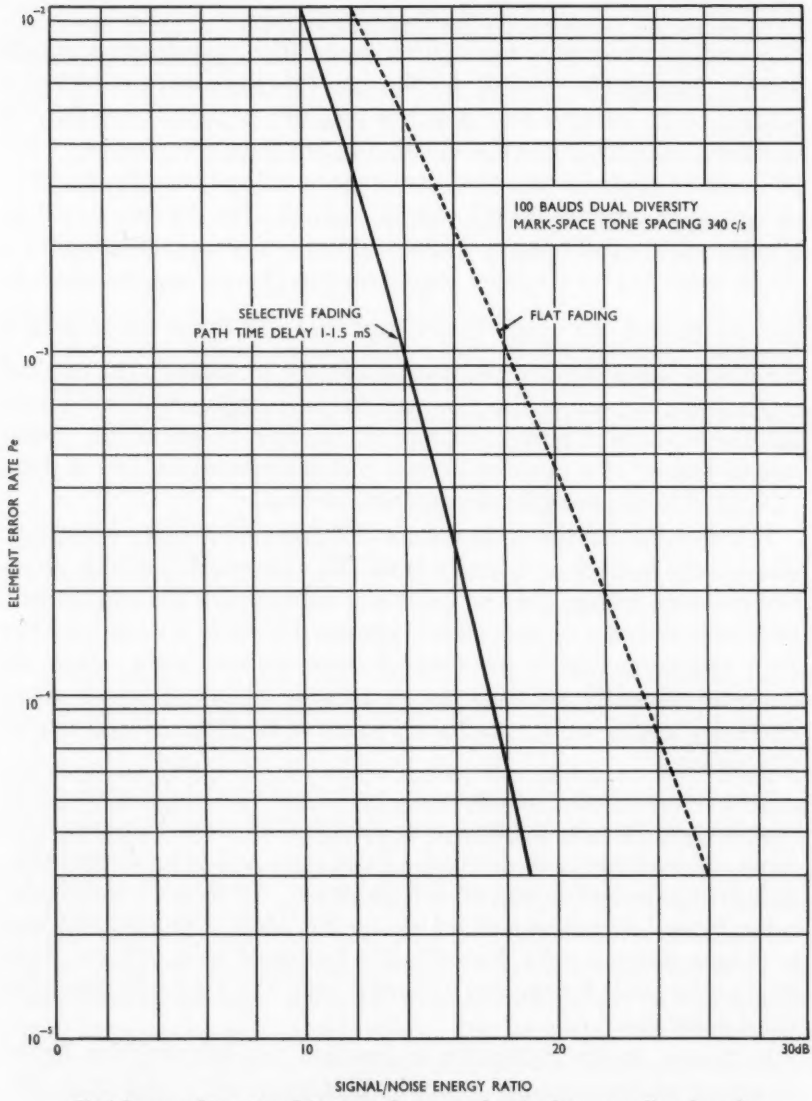


Fig.6. Improved two-tone detector performance showing frequency diversity gain

system. Nevertheless, it is the ability to operate effectively under conditions of severe selective fading that is the decisive factor on marginal telegraph circuits.

For optimum results, a two-tone detector should possess the following characteristics:

(a) The mark and space filters should each have the minimum bandwidth of B c/s.

(b) The detector should operate at a level halfway between the signal and noise levels. This will give the best noisy-signal performance.

(c) Each mark and space tone should be detected by a separate ON/OFF detector, thus obtaining the advantage of frequency diversity.

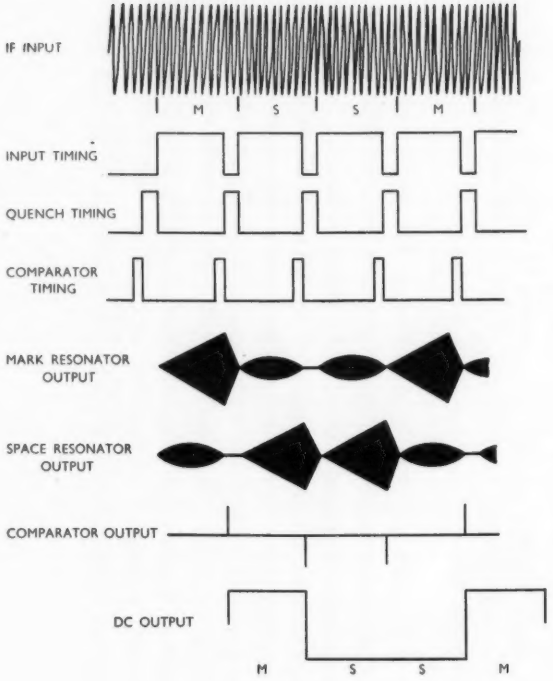
(d) The mark and space tones should be chosen to obtain the maximum frequency diversity advantage. For example, the tone separation should be 500 c/s for a radio route where the path time delay is 1 millisecond. Path time delays of 1 to 2 millisecond are common on long distance short wave routes, and thus the optimum tone separation will probably be between 500 and 250 c/s.

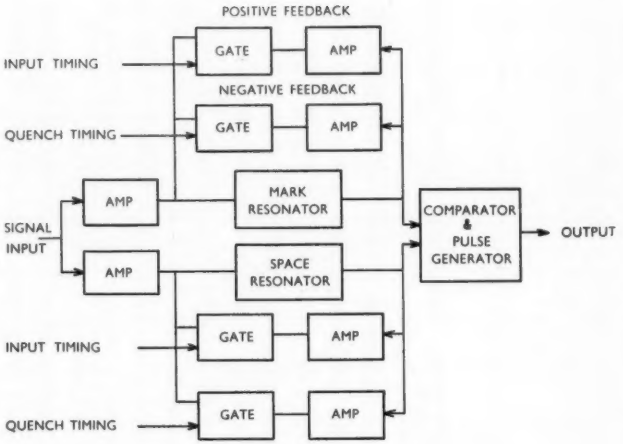
(e) The two detector outputs should be combined in such a way that each contribution is in proportion to its amplitude. The best results would be obtained if the 'ratio squaring' law as proposed by Kahn[6] were used. (Linear addition by means of two resistors is a much simpler arrangement which only loses 0·5 dB as compared with 'ratio squaring'.)

3.1.3 *The Predicted Wave System*

The predicted wave system is essentially a two-tone synchronous system using quenched resonators instead of bandpass filters.

Fig.7 shows the block schematic of the receiver demodulators. The receiver output is fed to two very high-Q resonators; one tuned to the mark frequency and the other to the space. When a mark element is fed to the mark resonator, the voltage across it will increase with time in a linear manner. During this time the output from the space resonator will pass through a number of maxima and minima, depending upon the length of the telegraph element and the frequency difference between





LEFT: Fig.7. Predicted wave detector system
RIGHT: Fig.8. Waveforms associated with predicted wave detector

the mark and space frequencies. This difference is chosen so that the output of the space resonator is zero at the end of the telegraph element. (For example, the frequency difference could be any multiple of 100 c/s for a telegraph speed of 100 bauds.)

About 2 milliseconds before the expected end of the mark element, the voltage across the two resonators is compared by a sampling pulse. If the mark voltage is the larger, the timing circuit produces a perfect mark element and vice versa. Immediately after the sampling pulse the two resonators are quenched to zero by applying heavy negative feedback, and they are then ready to receive the next signalling element. (See Fig.8)

The advantages of the system may be summarized as follows:

(a) The high-Q resonators integrate the signal perfectly in the presence of random noise, and the signal is examined at the end of each pulse when the signal/noise ratio is at a maximum. (However, simply because high-Q resonators are used it must not be thought that the bandwidth is infinitely narrow. It can be shown that the noise bandwidth of a quenched resonator is B c/s, see Fig.9.) Therefore we

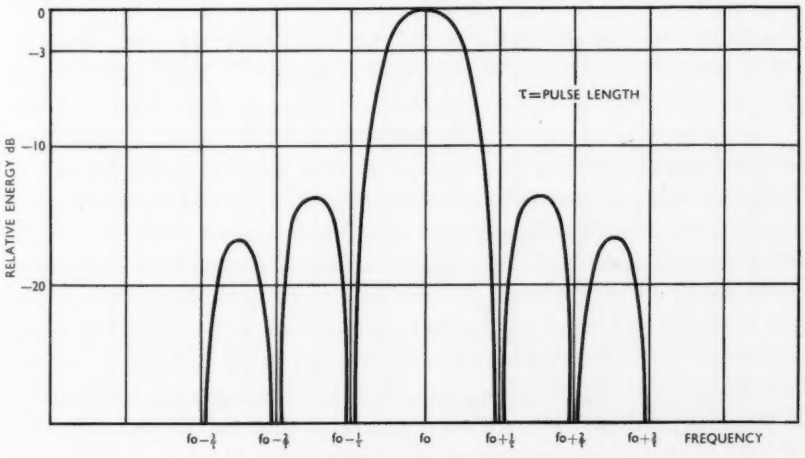


Fig.9. Selectivity curve of quenched resonator

would expect the demodulation factor to be good. From the information published it is about 3 to 3·5 dB.

(b) By sampling the mark resonator when the space is at zero and vice versa, the effective selectivity of the resonators is greatly increased. (This is of most use in multi-channel systems, since it reduces the cross-talk between channels.)

The system unfortunately possesses certain disadvantages:

(c) The system makes no use of the potential gain of frequency diversity.

(d) This system is essentially a synchronous system due to the need for quenching and sampling the resonators. Thus even on a noise-free radio circuit a start-stop signal cannot be used without the expense of synchronous transmission and reception.

3.2 FREQUENCY SHIFT MODULATION

The FSK detector consists essentially of a limiter driving a frequency discriminator. The output from the discriminator is limited, passed

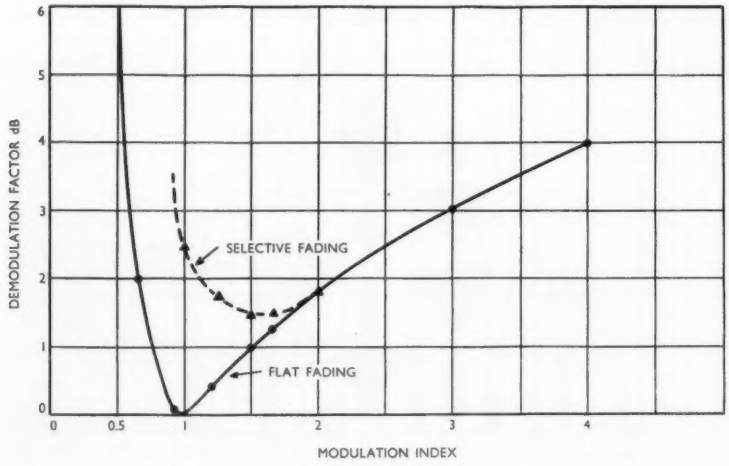


Fig.10. Demodulation factor VS modulation index for FSK system

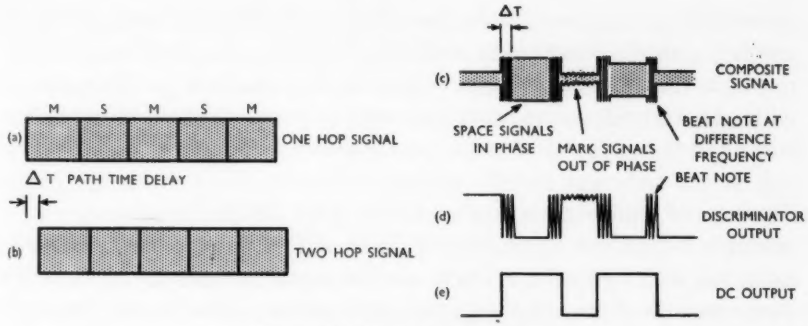


Fig.11. Waveforms for FSK system

through a low-pass filter and then further limited and used to key a double current output stage.

The reception of a non-fading FSK signal in the presence of noise is relatively simple. It can be shown that a modulation index M of unity (modulation index equals frequency shift in c/s divided by telegraph keying speed in bauds) gives optimum performance under these conditions (and in fact has a potential performance equal to an ideal detector) (see Fig.10). An increase of the modulation index above unity causes a slow deterioration of the demodulation factor, but the use of a modulation index of less than unity must be strictly avoided due to the rapid rise in the proportion of the total energy contained in the unmodulated carrier frequency component.

The reception of noisy FSK signals suffering selective fading presents many more problems. Fig.11 shows the waveform of the received signal, which is the result of the addition of the single-hop signal *a* and the two-hop signal *b* which is delayed by the time ΔT. The received signal *c* has mark and space elements which may or may not be in phase (thus giving frequency selective fading). During the intervals ΔT there is a period of overlap when both mark and space signals will be present, resulting in a component at the beat frequency of the two signals, and this gives rise to an indeterminate condition during this period. It is desirable to make this beat frequency sufficiently high that it may be

removed by a low-pass filter subsequent to the discriminator. In other words the modulation index should be increased; improvement in fact results as the modulation index is increased up to about 5. This conflicts with the noisy-signal requirement, stated above, that the modulation index and hence the bandwidth should be the minimum possible.

It is not sufficient merely to have minimum bandwidth; the phase response of the receiver must also be good. If the signal has severe selective fading, one signalling condition will be received at full amplitude, but the opposite condition will be greatly attenuated, and under these conditions, the signal must be presented unimpared to the detector.

It is also necessary to avoid a shift such that the mark is at a maximum when the space is at a minimum (i.e, 'flat' fading must be simulated as far as possible) since the error rate will be dictated by the smaller signal (this is quite contrary to the design criterion of the two-tone system). Where path delays do not exceed approximately 2 milliseconds, a modulation index of 2 appears a reasonable compromise, and this is supported by traffic trials.

Diversity reception is almost universally used in the reception of FSK signals. Unfortunately, the simple additive circuits which are satisfactory with ON/OFF or two-tone signals are not practicable, since the limiters have destroyed the amplitude relationship which determines the contribution each should make to the overall signal. Nor can the paths be combined at IF, as the two signals are in random phase relationship. Practical receivers frequently use path selection rather than combination[7], and it appears that this arrangement incurs a penalty of approximately 1 dB compared with the ideal arrangement of ratio squaring[1].

Using these techniques, double diversity receivers have been produced with a demodulation factor of 4 dB.

The parameters of an optimum FSK detector system can therefore be stated as follows:

(a) The modulation index should be about 2·0 for the reasons stated above.

(b) The pre-detector bandwidth should correspond closely to the theoretical minimum.

(c) The discriminator should be symmetrical about a frequency half-way between mark and space frequencies. (This ensures that noise does not give an unfair bias towards either mark or space.)

The use of rather more complex diversity combination or selection circuits is unfortunately necessary.

3.3 PHASE MODULATION

In all minimum bandwidth telegraph systems, the modulating waveform is sinusoidal. Under these conditions, phase modulation is identical to frequency modulation provided the two deviations are the same and reversals are sent. However, if steady mark or space is transmitted, the two signals differ. In the case of FSK signals, the mark or space frequency will be transmitted, but in the case of a phase modulated signal, the carrier frequency will be transmitted but with a difference in phase.

There is no difficulty in detecting whether a mark or space frequency is being received, but on HF systems it is only possible to detect a *change* of phase in the case of phase modulation. This is because it is very difficult to establish an absolute phase reference at the receiver. It has been shown by Voelcker[8] that, even in the absence of noise, there will be random changes in phase of the received signal due to the Rayleigh nature of the fading. A reference phase must, however, be available. This difficulty can be overcome by using the previous element as a phase reference (see Fig.12). This is known as the differentially-coherent detector and is the method used in a well-known phase modulated system[9]. In this particular system, binary information is usually encoded so that the phase of a succeeding element is unchanged when a space is transmitted, and changed by π for a mark element. Fig.13 shows the block schematic of this detector. Resonator 1 builds up in amplitude with the applied signal; at the end of the element, the signal is cut off, and the resonator 'rings' and stores the integrated phase of the received element. The next received element is applied to a second resonator. At the end of this element, the phase of the two resonators are compared, and the mark/space decision passed to pulse generators, which generate a perfect mark or space element.

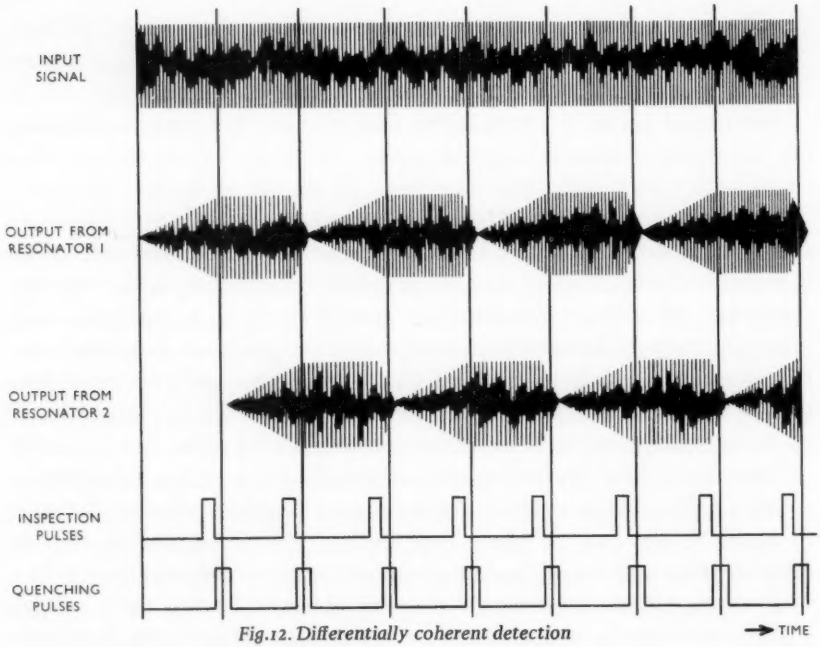


Fig.12. Differentially coherent detection

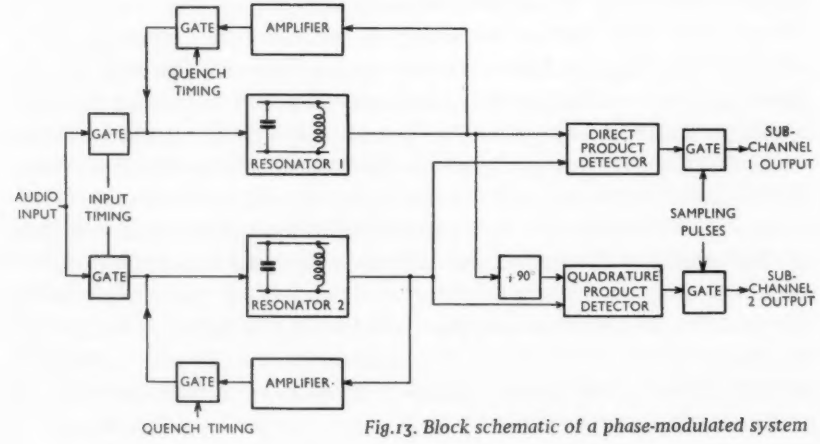


Fig.13. Block schematic of a phase-modulated system

This system has the maximum bandwidth utilization of any telegraph modulation process. Due to synchronous transmission and the method of detection, this system, in common with the predicted wave system, provides very high discrimination against frequencies suitably related to the keying speed. This shows to particular advantage on multichannel systems where bandwidth utilization far exceeds that of other systems. There are, however, certain disadvantages.

(a) An element error due to noise will not only cause an error in its own element but will give an erroneous phase reference for the next element. (This will only give a loss of about 1 dB for a non-fading signal, but will lose about 3 dB for the single-path fading case.)

(b) Even if the signal is free from noise, there will be a 'background count' of telegraph errors due to the phase perturbations of the fading signal[8].

(c) It can only be used on a synchronous signal. Moreover, where more than one channel is being transmitted, keying must also be in phase on all channels.

The 'background error count' corresponds to a minimum element rate, irrespective of circuit quality, of approximately 1 in 10^4. (1 in 2 000 characters.) This is unacceptable on commercial traffic circuits, and will therefore require the use of automatic error correction equipment. However, since all the errors occur in pairs, they cannot be corrected by using a 7-unit 3:4 code such as that used in the Van Duuren system, since this code is only capable of detecting 50% of double errors. If error correction is used, the code chosen must be one which is capable of detecting and correcting such double errors.

A demodulation factor of 3·5—4 dB is claimed for this system on a non-fading signal, but no results have been published showing comparative results on controlled tests with alternative systems.

4 COMPATIBILITY

Law carried out most of his work on the improved two-tone detector by receiving FSK transmissions having a shift of 400 c/s. It could easily be inferred that the reception of FSK signals by a two-tone AM detector is

always satisfactory. Conversely it might be imagined that two-tone signals could be received on a limiter-discriminator detector.

Full compatibility exists when the modulation index is relatively large (of the order of four or more) and the keying is relatively 'square'. For sine wave keying, and the ultimate narrow band system, the two are still compatible, but only when the fading is flat. (See Fig.14.) In the case of selective fading the systems are definitely not compatible as can be seen from Fig.15. The incompatibility arises from the fact that the frequency spectra of FSK and AM signals are different; in particular there is gradual change of phase from mark to space in FSK, whereas there is a discontinuity in the case of AM (i.e., phase coherence is an essential factor for correct detection by a discriminator under fading conditions).

5 BANDWIDTH EFFICIENCY

The increasing demands on the limited HF spectrum require optimum utilization of bandwidth, thus putting a high premium on bandwidth efficiency. Other things being equal, the system capable of transmitting the maximum information within a given bandwidth should be used.

An ideal system has been defined by Nyquist[10] as carrying 2 000 telegraph elements per second in a 1 000 c/s bandwidth. On this basis the alternative systems discussed in this article have a performance shown in Table III.

TABLE III

	ON/OFF	*Two tone ON/OFF*	*Predicted wave (AM)*	*FSK (M=1·7)*	*PM (2 phase)*
Bandwidth occupied by a single channel	B	2B	2B	2·7B	B
Number of 100 baud channels per kc/s of bandwidth	5·9	2·9	4	2·9	6·5
Bandwidth efficiency (%)	29·5	14·5	20	14·5	32·5

The bandwidth efficiencies given in Table III indicate the performance that may be achieved on practical equipment. Diplex operation has been

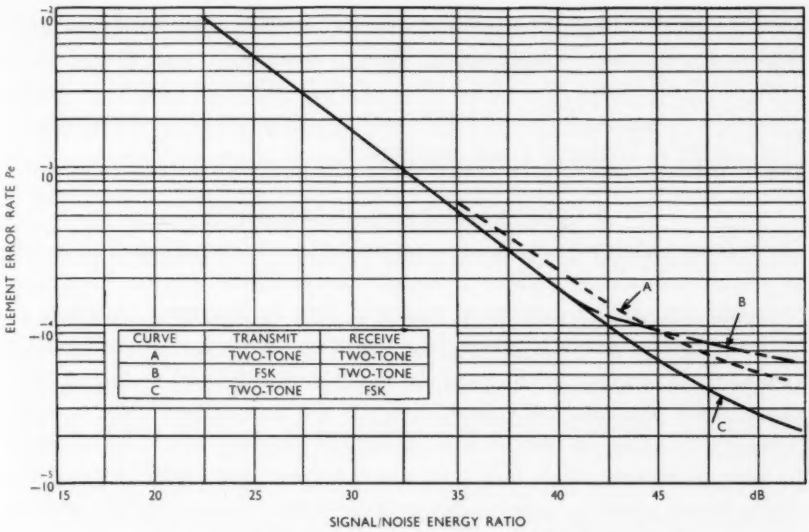


Fig.14. Compatibility of two-tone VS FSK at 100 bauds (flat fading)

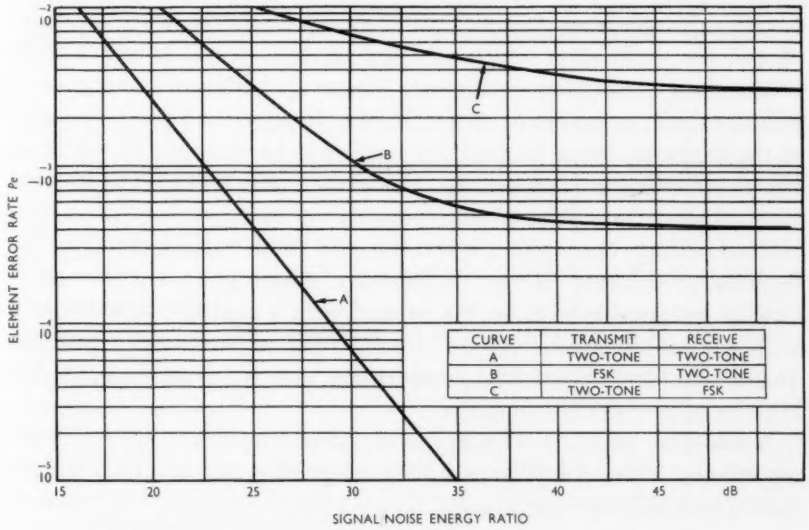


Fig.15. Compatibility of two-tone VS FSK at 100 bauds (selective fading)

used in conjunction with a phase modulated system, and this appears to require no increase in bandwidth. Under this condition of operation a bandwidth efficiency of 65% is attainable. In all other systems, diplex operation requires additional bandwidth, and this must be counted as a great factor in favour of phase modulation.

6 COMPARATIVE PERFORMANCE

There is no reason why modern receivers using A1 telegraphy should not be developed which achieve a demodulation factor approaching that obtained for other modulation systems. This is, however, unlikely as optimum performance requires close attention on the part of an operator (because the receiver gain must be accurately adjusted to the atmospheric noise level and the gain of diversity paths must be closely equal). It is expected that an optimum A1 telegraph receiver would be unlikely to have a demodulation factor of much better than 10 dB in practice, while many existing high-quality receivers have demodulation factors of between 15 and 20 dB for this type of service.

A frequency shift telegraph receiver could theoretically be designed having a demodulation factor of 0 dB. Demodulation factors of the order of 4 dB for modulation indices of approximately 2 are currently being obtained on production equipment. Frequency shifts of about 200 c/s will not result in excessive error-rates due to selective fading, although as the telegraph speed is increased above 100 bauds while maintaining constant modulation index, errors due to this cause will tend to increase substantially. This can be offset to some extent by increasing the value of shift to perhaps 600—750 c/s, but this will result in an increase in the demodulation factor. The predicted wave system gives a performance strictly comparable with an FSK system with a modulation index of 2 with, for a multichannel system at least, a higher bandwidth efficiency. This is offset by the practical disadvantage that synchronous operation must be used under all conditions.

A two-tone telegraph system has the same theoretical minimum demodulation factor (of 3 dB) as for A1 telegraphy, and practical designs exist which approximate to within 0·5—1 dB of this value. The problem

of ensuring constancy of path amplification is not so severe as with A1 telegraphy, since one of the two detectors are always being driven. It is when the effects of selective fading are taken into account that the full merit of the system is demonstrated, and much lower error rates (of the order of 10:1) are obtained, under comparable conditions, than with any other system. The bandwidth efficiency obtained is very similar to that provided by FSK systems using modulation indices of 1·5—2 (but both of these systems are markedly inferior to phase modulation in this respect).

Phase modulation can provide an extremely high bandwidth efficiency in both theory and practice, as telegraph channels of B bauds can be accommodated in channels separated by Bc/s. If diplex transmission (using phase quadrature) is used, a bandwidth efficiency of approximately 65% can be obtained. However, the limitations on accuracy imposed by the medium, and the requirement for synchronized operation identically phased on all channels are serious operational handicaps.

Extensive tests have been carried out over a 5000 mile path[11], and the results indicated a superiority of PM over FSK by a factor of approximately 2 in character-error-rate at low signal/noise ratios. However, at

TABLE IV

	A1	*Two-tone*	*Predicted wave*	*FSK (M=1·7)*	*PM**
Theoretical demodulation factor (compared with ideal)	3 dB	3 dB	3 dB	0 dB	3 dB
Practical demodulation factor	10—20 dB	3—4 dB	3—4 dB	3—4 dB	3—4 dB
Ability to combat selective fading	Fair	Excellent	Poor	Poor	Very poor
Background count element error rate (with moderate selective fading)	None	None	None	None	about 1 in 10^4

* For a differentially coherent detector.

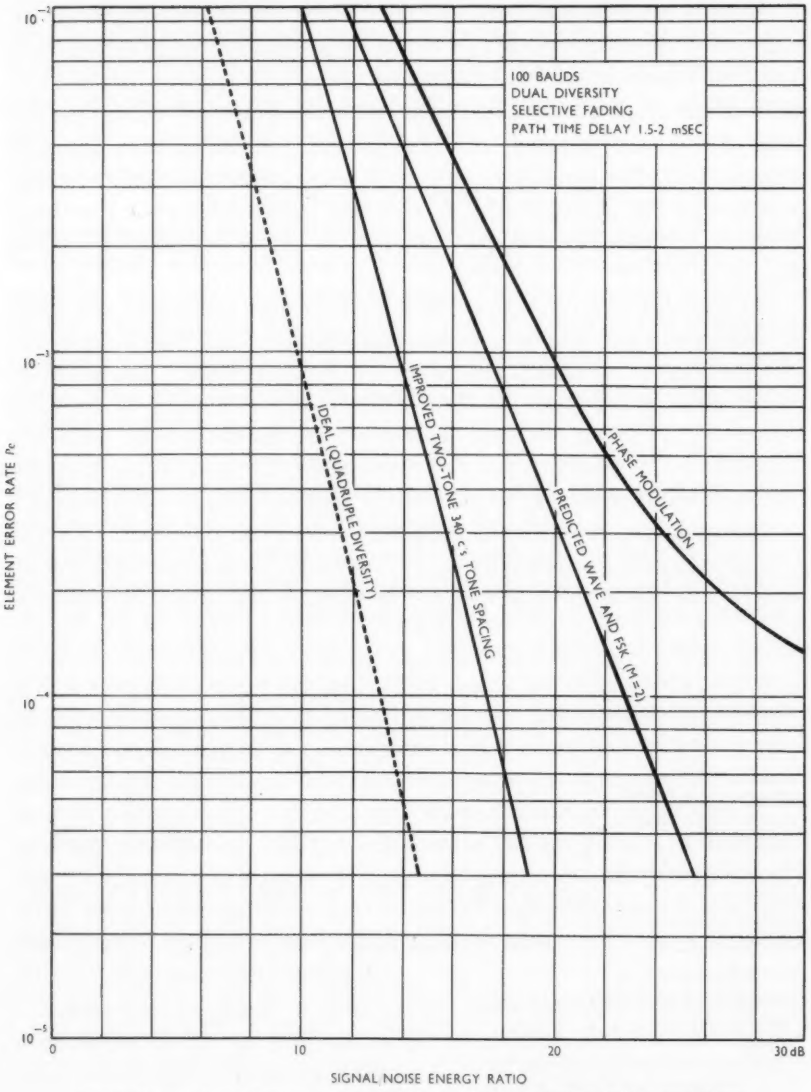


Fig.16. Comparison between systems under moderate selective fading conditions

signal/noise ratios exceeding about 35 dB, the FSK system was superior. These results are open to doubt as the synchronous PM system was compared with a non-synchronous FSK system having a modulation index of only 0·85. As has been shown in Section 2.3, a synchronous system itself gives an advantage of 5 times in error rate compared with a start/stop page printer. Correcting for this factor, it would appear that the PM system is in fact inferior at all signal/noise levels. Even when these are low and PM shows to best advantage, it is poorer by a factor of about 2.5:1. Table IV and Fig.16 show the comparative performance of these systems.

7 CONCLUSIONS

On balance there seems little doubt that for multichannel telegraphy, a two-tone system gives the best performance by quite a substantial margin, when high frequency propagation is involved. This applies also to single channel telegraphy, but in this case FSK gives quite good results especially when selective fading is not severe. Phase modulation is markedly inferior to these two systems, and in our opinion neither phase modulation or the predicted wave system are likely to realize their full theoretical advantage. In the case of phase modulation this is due to the inherent equipment complexity coupled with the need for error correction. In the predicted wave system, it suffers, to the same extent as the FSK system, from the requirement for both mark and space signals to be present at the detector for correct operation (though with greater ability to attain this due to freedom of allocation for the voice frequency tones, at least for multichannel systems).

Where a phase-stable medium such as landline, LF or microwave radio link is available this is no longer true, and there appears no doubt that a phase modulated system gives a satisfactory performance under operational conditions and offers vastly superior bandwidth utilization when compared with alternative systems.

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J. V. BEARD, born at Murree, Punjab, India, in 1919 and educated at Sir Anthony Browne's School, Brentwood. He obtained a degree in Electrical Engineering at Queen Mary College, University of London. In 1941 he joined the Marconi Company and was appointed to the Receiver Development Group in 1942. He has been responsible for the design of international class telegraph receivers, and is now well known as an authority on the design and development of terminal equipment, telegraph and telephone receivers.

A. J. WHEELDON, born near Reading, England. He was educated at City of London School and Oxford University. During the war he was at the Royal Aircraft Establishment, Farnborough. After the war he was engaged in the development of equipment using television and guided missile control techniques. In 1952 he joined the British East Africa Corporation of Kenya and was engaged in System Planning work for VHF systems. In 1954 he joined the Marconi Company as a member of Communications Division. For three years he has acted as Editor of *Point to Point Telecommunications*. He is now responsible for the Company's Technical Publications and has been appointed the member of the Company responsible for C.C.I.R matters.

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Fur unsere deutschsprechenden Leser veröffentlichen wir eine kurze Abfassung in deutscher Sprache von den Aufsätzen, die in dieser Ausgabe erscheinen.

SEITE 2

STANDPUNKTE

Seit den Anfängen der Funktechnik nahm man schlechthin an, dass die Geräte in der Lage waren in jeder vorgefundenen Umgebung betrieben werden zu können. Dies war nicht schwierig zu einer Zeit, als die Anforderungen noch verhältnismässig unkompliziert waren, weil die Geräte auf jeden Fall einfach und robust waren und die Betriebstoleranzen grosse Temperatur- und Feuchtigkeitsänderungen ohne grosse Schwierigkeiten zuliessen. Die Auswirkungen von Staub und Insekten wurden als lästig empfunden und die Geräte mussten so gebaut werden, dass sie diesen Auswirkungen standhalten konnten, ohne das Wartungspersonal zu sehr in Anspruch zu nehmen. Die Möglichkeit der Belüftung wurde nicht in Erwägung gezogen.

Die Gerätevorschriften verlangen in vielen Fällen immer noch eine Widerstandsfähigkeit gegen stark veränderliche Umgebungseinflüsse, selbst wenn ein strenger Masstab an die Leistungsfähigkeit gelegt wird. Dies wurde bis etwa zum Jahre 1950 auch auf das Fernsprechgebiet angewandt. Dann zeigte sich jedoch besonders auf dem Gebiet der Wählämter mit vielen elektromechanischen Anlagen, dass diese Einstellung wegen der grossen Fehlerhäufigkeit und der hohen Ersatz- und Wartungskosten sehr viel Geld kostete. Es ist interessant festzustellen, dass dieses Problem zuerst von den Fernsprechingenieuren ernsthaft beachtet wurde, weil hauptsächlich tropische Gebiete, in denen dieses Problem sehr stark in Erscheinung tritt, gewöhnlich diejenigen sind, die im allgemeinen auf europäische und amerikanische Erfahrung angewiesen sind. Die Grösse des Problems kann vielleicht dadurch am besten ermessen werden, dass die Einführung der Belüftung dort als wirtschaftlichste Lösung für einen zuverlässigen Betrieb über lange Zeit hinaus betrachtet wurde.

Erst sehr viel später, wenn überhaupt, wurde die Ratsamkeit einer gewissen Belüftung für Funkgeräteräume im einzelnen in Erwägung gezogen. Grundsätzlich bleibt dies eine Frage der Wirtschaftlichkeit. Die Einsparungen an Anlagekosten und späteren Pflegekosten durch die Benutzung einer Belüftung können überraschend gross sein. Wenn diese Vorteile mit der Verknappung von gelerntem Pflegepersonal kombiniert werden, dann ergibt sich ein klarer Vorzug für die Begrenzung der Umgebungsbedingungen durch eine Belüftung. In einem besonderen Falle ergab sich eine Einsparung von ungefähr 15% in den Anlagekosten durch Verringerung der maximalen Temperaturgrenze von 75°C auf 55°C und durch Erleichterung der Bedingungen für die Imprägnierung. Obwohl dies eine Ausnahme sein mag, werden damit wenigstens die Kosten für eine Erhöhung der Grenztemperatur um 15-20°C illustriert.

In einigen Fällen kann die geforderte Leistungsfähigkeit über den bei möglichen Einsatzstellen zu erwartenden Temperatur- und Feuchtigkeitsbereich nicht erreicht werden (oder nur mit untragbaren Kosten). Als Beispiele mögen erwähnt werden: Steuersender mit hoher Frequenzkonstanz und Hohlraum- oder Hohlrohrfilter zur Erreichung hoher Trennschärfe in Mikrowellenanlagen.

Es ist paradox, dass gerade die billigeren und einfacheren Geräte den schlimmsten Bedingungen unterworfen sind, da es unrealistisch ist selbst die einfachste Belüftungsform in den meisten kleinen Sende- und Empfangsstationen, in denen solche Geräte Verwendung finden, zu erwarten.

SEITE 4

ANWENDUNGEN VON FERRITRESONANZ-EINWEGLEITUNGEN

von E. F. Schelisch

Einwegleitungen sind Mikrowellenschaltungselemente, welche reflektierte Wellen von dem Generator, der die Vorwärtswelle erzeugt, fernhalten. Es wurde festgestellt, dass sich mit gewissen Ferriten nichtreziproke Effekte bei Mikrowellen erzeugen lassen. Ferritresonanz-Einwegleitungen benutzen die Resonanz des Elektronspins als gyromagnetischen Effekt für die Erzeugung einer nichtreziproken Absorption.

Ein Elektronspin kann mit einem elektromagnetischen Feld nur dann gekoppelt werden, wenn letzteres einen hauptsächlich zirkular polarisierten Feldanteil enthält. Diese Ferritresonanz macht es erforderlich, dass die Frequenz des Spins und des Feldes gleich sein müssen. Die Spinfrequenz kann durch ein angelegtes äusseres magnetisches Gleichfeld eingestellt werden.

Die Bandbreite solcher Schaltungselemente hängt von den Eigenschaften des Ferrits und anderen Konstruktionsdaten ab. Bei praktischen Anwendungen lässt sich eine Bandbreite von 10% leicht erreichen. Ein Mittelwert für die Rückwärtsdämpfung ist 20dB bei einer Vorwärtsdämpfung von 0.5-1dB. Das Verhältnis der beiden Werte ist gewöhnlich höher bei höheren Frequenzen.

Ferrit-Einwegleitungen werden mit Vorteil in Mikrowellen-Messgeräten verwendet, wo sie den Messbereich dadurch erhöhen, dass Dämpfungsglieder überflüssig werden. (Diese haben normalerweise eine Dämpfung von 10dB in beiden Richtungen, um die Oszillatorfrequenz bei stark veränderlicher Last konstant zu halten).

Eine der vielversprechendsten Anwendungen von Ferrit-Einwegleitungen liegt auf dem Gebiete der Richtfunkanlagen mit Frequenzmodulation. Verzerrungen und damit Übersprechen in den Grundkanälen treten dann auf, wenn Reflektionsstellen in langen Antennenspeiseleitungen einen Teil der Wellen reflektieren. Einwegleitungen werden mit Erfolg zur Bedämpfung solcher Reflektionen benutzt und erlauben damit eine Verbesserung bestehender Anlagen oder bei vorgeschriebener Leistungsfähigkeit eine Kostensenkung bei neuen Anlagen.

Ein anderes Anwendungsgebiet ist der sogenannte Maser, wo das Ausgangssignal vom Eingangssignal getrennt werden muss. Ausserdem können bei Mikrowellenmischstufen die Auswirkungen von Kombinationsfrequenzen reduziert werden.

SEITE 11

EFFEKTE DES SONNENUNTERGANGES IN DER GEGEND DES ÄQUATORS

von A. M. Humby

Zu Zeiten erhöhter Sonnenfleckentätigkeit und in den Monaten um die Tag- und Nachtgleiche traten unerwartete Schwierigkeiten beim Empfang von Kurzwellentelegraphie über grosse Entfernungen auf. Bei Entfernungen über 4000km erfolgt die Ausbreitung über eine Reihe von komplexen Wegen und es wurde empirisch ermittelt, dass bei enier gegebenen Frequenz die Ausbreitung gewöhnlich mittels der F_2-Schicht erfolgt, solange die Ionosphäre an Arbeitspunkten, die etwa 2000km von jeder Endstelle entfernt liegen (siehe Abb. 2), eine Übertragung bei dieser Frequenz gewährleistet, unabhängig von der Beschaffenheit der Ionosphäre auf dem ubrigen Teil des Grosskreises. In gewissen Fällen ist eine Übertragung mittels der E-Schicht möglich. Deren Untersuchung erfordert zwei zusätzliche Arbeitspunkte im Abstand von ungefähr 1000km von jeder Endstelle.

Diese Betrachtungsweise liefert nun sehr genaue Vorhersagen über die Ionosphäre. Vorhersagen dieser Art für die Linie Singapur-London im August 1947 sind in Abb. 3 wiedergegeben. Ein grosser Frequenzbereich scheint in der Zeit von 1200-1400 GMT, d.h. 1900-2100 Ortszeit benutzbar zu sein. Tatsächlich war jedoch die Verbindung wegen zu vieler Reflektionen schwierig, wenn nicht unmöglich. Obwohl die Stärke der Signale gross war, unterlagen diese jedoch einer starken horizontalen Streuung bei der äquatorialen Endstelle und zwar für ungefähr zwei Stunden während des örtlichen Sonnenunterganges am äquatorialen Arbeitspunkt. Dies trat nur während der Monate um die Tag- und Nachtgleiche auf und zwar in den Jahren starker Sonnenfleckentätigkeit, wie aus den Abbildungen 4a und 4b ersichtlich ist. Ähnliche, aber weniger hervorstechende Ergebnisse wurden auf der Linie London-Colombo gefunden.

Diese Ergebnisse bekräftigen die Beobachtungen von Osborne[1], der vermutet, dass dieses Phänomen wahrscheinlich durch die Auflösung der F_2-Schicht bei Sonnenuntergang in der äquatorialen Gegend ausgelöst wird. Seltsamerweise tritt dieser Effekt am stärksten während der Monate der Tag- und Nachtgleiche zu Zeiten des Maximums der Sonnenflekkentätigkeit auf.

SEITE 20

EIN VERGLEICH ZWISCHEN VERSCHIEDENEN KURZWELLEN-TELEGRAPHIE-SYSTEMEN

von J. V. Beard and A. J. Wheeldon

Bis vor kurzer Zeit lagen keine absoluten Normen für einen Vergleich zwischen Kurzwellentelegraphiesysteme vor. Der beliebteste Ausgangspunkt war eine Zählung des Zeichenelementanteils, welcher um mehr als einen bestimmten Betrag verzerrt wur de. Law[1] schlug im Jahre 1957 einen Vergleich mit einem 'idealen Detektor' vor, der die minimale theoretische Fehlerhäufigkeit hatte. Der vorliegende Aufsatz befasste sich mit einem Vergleich der Leistungsfähigkeiten praktischer Systeme

in Bezug auf einen idealen Detektor unter Berücksichtigung veröffentlicher Angaben.

Das kritische Element in einem System ist der Empfänger. Ein Empfänger für Frequenzumtastung kann zur Fehleranzeige benutzt werden, wenn der Rauschpegel am Begrenzer den Signalpegel überschreitet. Dies kann in absoluter Weise durch das Rauschleistungsverhältnis ausgedrückt werden, welches das Verhältnis der Leistung in einem einzelnen Zeichenelement zu der Rauschleistung je Bandbreiteneinheit darstellt. Gleichung (3) drückt dies aus. Der Faktor b, welcher den Verschlechterungsfaktor des praktischen Detektors gegenüber dem idealen Detektor darstellt, wird Demodulationsfaktor genannt. Bei Schwunderscheinungen lässt sich die Fehlerhäufigkeit durch die Gleichungen (4) und (5) für einfachen und doppelten Diversitätsempfang angeben. Der Demodulationsfaktor von praktisch benutzten Empfängern kann im Laboratorium unter Benutzung einer 'Schwundmaschine' (Abb. 2) gemessen werden.

Zur Erzielung der besten Ergebnisse darf der Empfänger nur die Signalleistung durchlassen und muss unnötige Rauschleistung ausschliessen. Die Verstärkung und der Rauschfaktor brauchen nur die Bedingungen für ungehinderten Betrieb an einem Ort mit möglichst niedrigen atmosphärischen Störungen zu erfüllen. Die Erreichung von Rauschfaktoren, die unter den in Tabelle II angegebenen Werten liegen, erscheint nicht notwendig zu sein.

Für viele Jahre wurde A1-Telegraphie benutzt, jedoch müssen die Empfänger laufend in ihrer Verstärkung auf beste Betriebsweise nachgeregelt werden. Sie sind den Anlagen für konstante Leistung, wie Doppeltontelegraphie und Telegraphie mittels Frequenzumtastung, unterlegen. Die erreichten Demodulationsfaktoren sind bis zu 15-20 dB selbst bei guten modernen Empfängern. Die Doppeltontelegraphie, bei der ein Ton durch den Zeichenschritt und der andere durch den Trennschritt moduliert wird ist weit besser, da die gesamte Information in jedem der beiden Töne enthalten ist, die so gewählt werden können, dass ein Ton im Maximum liegt, während der andere durch Schwund stark beeinflusst wird. (Eine Frequenzdifferenz von 300 Hz und 500 Hz liefert normalerweise die besten Ergebnisse). Mit dieser Art von Empfänger lassen sich Demodulationsfaktoren von 3-4 dB erreichen.

Das System mit Frequenzvoraussage benutzt Superregenerativ-Resonatoren zur Feststellung der beiden Töne für den Zeichenschritt und den Trennschritt (siehe Abb. 7 und 8). Dieses System arbeitet mit Gleichlauf und die Töne müssen ein geeignetes Verhältnis zur Modulationsgeschwindigkeit haben, um während des Zeichenschrittes einen Nullausgang vom Trennschrittresonator zu erhalten und umgekehrt. (Z.B. bei einer Zeichenelementlänge von 10 msec. müssen die Töne einen Frequenzunterschied vom Vielfachen von 100 Hz haben). Dieses System scheint einen Demodulationsfaktor von ungefähr 3 dB zu haben. Es kann jedoch starken selektiven Schwund schlecht verarbeiten.

Die Anlagen mit Frequenzumtastung haben einer theoretischen Demodulationsfaktor von 0 dB. Werte von 4 dB wurden mit Empfängern aus der Produktion erreicht. Ausgezeichnete Leistungen lassen sich dort erreichen, wo der Schwund nicht zu stark ist. Unter diesen Umständen zeitigt ein Modulationsindex von 2 die besten Ergebnisse.

Phasenmodulation ist mit einer Bandbreitenersparnis verbunden, die von keinem anderen System erreicht wird. Sie lässt sich jedoch nur schwer in der Kurzwellentelegraphie anwenden, weil im Empfänger eine Bezugsphase vorhanden sein muss, da nur Änderungen der Phase übertragen werden. Bei Kurzwellen ist das Übertragungsmedium nicht stabil genug, um im Empfänger eine Bezugsgrösse verwenden zu können. Dies kann dadurch überwunden werden, dass die Phase eines Zeichenelementes als Bezugsgrösse für das nächste Zeichenelement dient (siehe Abb. 13). Trotzdem entstehen noch Fehler und in guten Verbindungen entstehen selten weniger Fehler als 1 in 10^4 Zeichenelementen.

Die Frequenzumtastung ist zur Zeit am meisten verbreitet und liefert ausgezeichnete Ergebnisse, wenn der Schwund nicht zu stark ist. Das System mit Frequenzvorhersage hat eine damit vergleichbare Leistungsfähigkeit, jedoch mit erheblich mehr Frequenzbandeinsparung. Da aber theoretische wie auch praktische alle Zeichenelemente am Demodulator auftreten müssen, sind die mit diesen beiden Verfahren erzielbaren Ergebnisse nicht so gut wie beim Doppeltonverfahren, wenigstens in seiner neuesten Ausführung[4]. Dieses Verfahren hat von allen mit grossem Vorsprung die beste Leistungsfähigkeit bei Schwunderscheinungen (siehe Abb. 16). Die Phasenmodulation scheint bei Kurzwellenverbindungen wegen der Instabilität des Übertragungsmediums keine praktische Bedeutung zu haben. Wo dieses Problem nicht auftritt, wie z.B. bei Drahtverbindungen oder Langwellen-Funkverbindungen, wird dieses im Hinblick auf die aussergewöhnliche Bandbreitenersparnis wahrscheinlich das beste Verfahren sein (siehe Tabelle III).

Presentamos este sumario de los articulos publicados en este número, redactado en castellano especialmente para nuestros lectores de habla castellana.

PAGINA 2

PUNTOS DE VISTA

Desde que existe la radio, se ha venido reconociendo que cada equipo debe poder operar bajo las circunstancias presentes en el sitio en que se encuentra el mismo. Ello no presentaba dificultades cuando los requerimientos del rendimiento eran relativamente modestos, porque en todo caso el equipo era de por sí sencillo y resistente, y las tolerancias de operación eran tan amplias que las grandes variaciones de temperatura y humedad ambientes se toleraban sin mayor dificultad. Los efectos del polvo atmosférico y de los insectos se consideraban molestos y el equipo se fabricaba de manera que pudiere tolerar los efectos de aquéllos sin excesivas demandas al personal encargado de la manutención. Ni se llegaba a considerar la posibilidad de usar aire acondicionado.

Las especificaciones para equipos, en muchos casos, siguen demandando una resistencia a grandes variaciones de condiciones en el sitio de operación, aún cuando se pide un rendimiento sumamente elevado. Esta situación prevalecía también, quizás hasta 1950, en el campo telefónico, pero para el tiempo de que se habla se había hecho evidente que especialmente en el caso de las centrales automáticas con grandes cantidades de equipos electromecánicos, dicha política venía costando mucho dinero en términos de las excesivas fallas de los equipos y los elevados costos de reposición y manutención. Es interesante observar que este problema fué encarado serimente en un primer tiempo por los ingenieros telefónicos, debiéndose esto a que esas zonas principalmente tropicales, donde el problema es más agudo, son generalmente las que más buscan una guía en la experiencia europea ó norteamericana. Talvéz sea una medida de la magnitud del problema el hecho de que la vanguardia en la introducción del acondicionamiento de aire fué tomada por aquellos como la solución más económica del modo de ofrecer un servicio seguro a largo plazo.

Sólo mucho más recientemente, y apenas ahora, se ha llegado a considerar en detalle la conveniencia de usar al menos en cierto grado el aire acondicionado en las salas de equipos de radio. Básicamente, ésta será siempre una cuestión económica. La reducción del costo inicial del equipo y los gastos de mantención subsiguientes gracias al uso de acondicionamiento de aire puede ser sorprendentemente grande. Cuando estas ventajas se combinan con una escasez de ingenieros de servicio idóneos, resulta sumamente conveniente buscar de reducir la amplitud de las variaciones climáticas del sitio por medio del aire acondicionado. En un caso específico, pudo reducirse en aproximadamente un 15% el costo inicial de un equipo al limitarse el rango de temperaturas toleradas por las piezas componentes de 75°C á 55°C y al reducir las especificaciones referentes a la impregnación de las mismas. Aunque ésta puede haber sido una excepción, sirve a lo menos de ilustración del costo de un aumento de 15 á 20°C al límite superior de la temperatura ambiente.

En algunos casos el rendimiento deseado no puede lograrse en todo el rango de temperatura y humedad que se anticipa en el sitio donde podría instalarse el equipo (ó podría obtenerse a un costo prohibitivo). Lo dicho queda talvéz confirmado donde se emplean excitadores muy estables para transmisores, ó en equipo micro-onda en que se usan filtros de cavidad ó de guía de onda para conseguir la selectividad necesaria.

Paradójicamente, seguirá siendo el equipo más económico y sencillo el que tenga que soportar condiciones que pueden ser realmente arduas, puesto que no es realístico pretender acondicionamiento de aire aún sencillo en las estaciones transmisoras y receptoras más pequeñas, que es donde siempre se usará éste tipo de equipo.

PAGINA 4

APLICACIONES PARA LOS AISLADORES DE RESONANCIA DE FERRITA

por E. F. Schelish

Los aisladores son elementos de circuitos micro-onda que aislan las ondas reflejadas del generador que ha producido la onda incidente. Se ha comprobado que las propiedades giro-magnéticas de ciertos materiales de ferrita permiten la obtención de fenómenos no-recíprocos en las frecuencias correspondientes a micro-ondas. Los aisladores de resonancia de ferrita hacen uso de la resonancia de rotación de electrones como el efecto giro-magnético para la producción de absorción no-recíproca.

La rotación electrónica puede actuar recíprocamente con un campo electromagnético sólo cuando éste último posee una componente de polarización substancialmente circular. Este resonancia de la ferrita implica que las resonancias tanto del giro como de la onda son iguales. La frecuencia del giro puede regularse mediante un campo magnético constante de aplicación externa.

El ancho de banda de éste tipo de dispositivo depende de las propiedades de la ferrita y de otros detalles del proyecto, y en la práctica es dable obtener un ancho de banda del 10%. Una cifra promedio representativa de la pérdida de retorno sería 20dB, con una pérdida hacia adelante de 0,5 á 1dB. La relación de las dos cifras es generalmente más elevada en las frecuencias mas altas.

Los aisladores de ferrita pueden emplearse muy ventajosamente en los equipos de medición de micro-ondas, en los cuales aumentan el alcance de las mediciones posibles al prescindir del uso de atenuadores (los que normalmente introducen una absorción de unos 10 db en la dirección de emisión a fin de estabilizar la frecuencia del oscilador bajo condiciones de carga ampliamente variables).

Una de las aplicaciones más interesantes de los aisladores de ferrita se halla en los equipos de enlace multicanales en micro-ondas que usan la modulación en frecuencia. La modulación en frecuencia es distorsionada, y en consecuencia se produce modulación cruzada entre los canales de la banda básica, cuando los 'mismatches' (desequilibrios) en los alimentadores largos de antena producen reflexiones. Los aisladores pueden usarse con éxito para la reducción de dichas reflexiones, permitiendo así la mejora de instalaciones existentes ó una economía capital en instalaciones nuevas para un nivel dado de rendimiento.

Otros campos de aplicación se encuentran en los 'Masers', para aislar la salida de las señales de entrada, y en los mezcladores micro-onda, para reducir los efectos de las frecuencias de combinación.

PAGINA 11

EFECTO DE LA PUESTA DE SOL ECU \TORIAL

por A. M. Humby

Durante losperiodos de maximas manchas solares, y en los meses vecinos al equinoccio, se han manifestado dificultades inesperadas en la recepción de transmisiones telegráficas a AF sobre largas distancias. Para distancias mayores de 4000Km, la propagación tiene lugar por una serie de modos complejos, y se ha comprobado empíricamente que, para una frecuencia dada la propagación por la capa F_2 es generalmente práctica en tanto que la ionosfera en 'puntos de control' distantes a 2000Km de cada terminal (vere Fig.2) soporte la transmisión a esa frecuencia independientemente de la condición de la inosfera en otras partes por encima de la senda del gran círculo. En ciertos casos puede resultar posible la propagación por la capa E, y su investigación requiere el uso de dos 'puntos de control' adicionales distantes a 1000Km de cada terminal.

Esta línea de investigación ya está dando pronósticos inonosféricos de bastante precisión; las predicciones de este tipo para el circuito Singapur-Londres para Agosto de 1947 se ilustran en la Fig 3. Parece ser factible el empleo de una amplia gama de frecuencias durante el período de 1200—1400 horas del Meridiano de Greenwich, correspondiente a las 1900—2100 horas del horario local, pero en realidad la comunicación fué difícil, si no imposible, debido al enlace excesivo. Las señales, aunque eran de alto nivel, sufrieron una dispersión azimutal considerable en el terminal ecuatorial durante unas dos horas a la puesta del sol en el 'punto de control' ecuatorial. Ello ocurrió solamente en los meses equínocciales, durante los años de mucha actividad de las manchas solares, como se ilustra en las Figs. 4a y 4b. Ocurren resultados similares, pero menos pronunciados, en la ruta Londres—Colombo.

Estos resultados corroboran las observaciones de Osborne[1], quien sugiere que el fenómeno puede ser debido a la desintegración de la capa F2 a la puesta del sol en la región ecuatorial. Es curioso notar que dicho efecto es más pronunciado durante los meses equinocciales y en los períodos de máximas manchas solares.

PAGINA 20

UNA COMPARACION DE SISTEMAS TELEGRAFICOS DE AF

por J. V. Beard y A. J. Wheeldon

Haste época reciente no existía norma alguna de comparación absoluta de sistemas telegráficos de AF; el fundamento que se empleaba más frecuentemente era el de contar la proporción de los elementos deformados por sobre cierta cantidad arbitraria. Law[1] propuso en 1957 una comparación en términos del 'detector ideal', es decir el que ofreciere la

proporción minima de error teórico. El articulo compara el rendimiento de sistemas prácticos en términos del detector ideal, a la luz de información publicada.

El elemento crítico de cualquier sistema es el receptor. El receptor de FSK (acople por desplazamiento de frecuencia) puede registrar un error cada vez que el ruido en el limitador excede a la señal. El mismo puede expresarse de manera absoluta en términos de la 'relación de la energía de señal/ruido', que es la relación de la energía en un sólo elemento telegráfico con la potencia del ruido por unidad de amplitud de banda; la misma aparece en la ecuación (3). El factor *b*, que registra la cantidad en que un detector práctico es inferior a uno ideal, es llamado el Factor de Demodulación. Cuando se manifiesta el desvanecimiento, la relación del error está dada por (4) y (5) con respecto a diversificación simple y doble. El factor de demodulación de receptores prácticos puede medirse en laboratorio mediante el empleo de una 'máquina de desvanecimiento' (ver Fig. 2).

Para obtener los mejores resultados, el ancho de banda del receptor debe admitir únicamente la energía de la señal, excluyendo el ruido innecesario. El factor de ganancia y de ruido podrá tener sólo el valor suficiente como para ofrecer un rendimiento inalterado en el sitio de operación que ofrezca el menor ruido atmosférico posible. Parece ser innecesario lograr factores de ruido menores de los señalados en la Tabla II.

La telegrafía A1 se viene usando desde hacen muchos años, pero los receptores requieren ajustes contínuos para un rendimiento óptimo, y son inferiores a los sistemas de potencia constante, como son la telegrafía de dos tonos o la telegrafía a desplazamiento de frecuencia. Los factores de demodulación conseguidos llegan hasta 15 ó 20dB, aún en buenos receptores de modelo reciente. El sistema de dos tonos, en que un tono está acoplado para señal de 'marca' y el otro para 'espacio', es muy superior al anterior, ya que toda la información está contenida en cada uno de los tonos, pudiendo elegirse a éstos de manera tal que uno esté al máximo mientras el otro se halla más afectado por el desvanecimiento (una diferencia de entre 300 y 500c/s generalmente ofrece los mejores resultados). Con éste tipo de receptor pueden obtenerse factores de demodulación de 3 – 4dB.

El sistema predictor de onda emplea resonadores saturados para la detección de los dos tonos usados para las señales de 'marca' y 'espacio' (ver las Figs. 7 y 8). El sistema es sincrónico, y los tonos deben relacionarse adecuadamente a la velocidad de acople ó manipulación para asegurarse una salida cero del resonador de 'espacio' con las señales de 'marca' y vice-versa. (Por ejemplo, con una duración de 10mSeg del elemento, los tonos deben estar distanciados por un múltiplo de 100c/s). Este sistema parece brindar un factor de demodulación de alrededor de 3dB, pero no puede resistir el desvanecimiento selectivo severo.

El sistema a desplazamiento de frecuencia puede ofrecer un factor de demodulación teórico de 0dB, y en receptores de serie se han obtenido valores de 4dB. Se puede obtener un rendimiento excelente cuando el desvanecimiento selectivo no es muy pronunciado, y en tales condiciones un índice de modulación de 2 brinda resultados óptimos.

El sistema modulado en fase ofrece una economía del ancho de banda que notiene par en ningún otro sistema, pero se lo puede aplicar sólo con dificultad en sistemas telegráficos de AF porque, dado que se transmiten únicamente los *cambios* de fase, debe disponerse de una fase de referencia en el receptor. En AF el medio de propagación no es suficientemente estable como para permitir una referencia local en el receptor, y ello se supera usando la fase de un elemento como referencia para el siguiente (ver Fig.13). Con todo ello, los errores surgen aún, y hasta en buenos circuitos los mismos raras veces son superiores a 1 en 10^4 elementos.

El sistema de desplazamiento de frecuencia es el más usado en la actualidad, ofreciendo resultados excelentes cuando el desvanecimiento selectivo no es demasiado pronunciado. El sistema predictor de onda ofrece resultados comparables, pero con una eficiencia de amplitud de banda algo mayor. Sin embargo, ya que todas las componentes de la señal deben estar presentes en el detector – tanto en teoría como en la práctica – los resultados del uso de estos dos sistemas no alcanzan a ser tan buenos como los del sistema de dos tonos, por lo menos en lo que respecta a la forma más moderna del mismo[4]. Este tipo de sistema ofrece con mucho el mejor rendimiento de cualesquiera de los sistemas en condiciones de desvanecimiento (ver la Fig. 16). No se considera a la modulación de fase como solución práctica para los circuitos telegráficos de AF, debido a la inestabilidad de fase del medio, pero cuando ella no se manifiesta, como en líneas terrestres ó sistemas de radio de BF, probablemente la misma será la más satisfactoria, en vista de su excepcional eficiencia de amplitud de banda (ver Tabla III).

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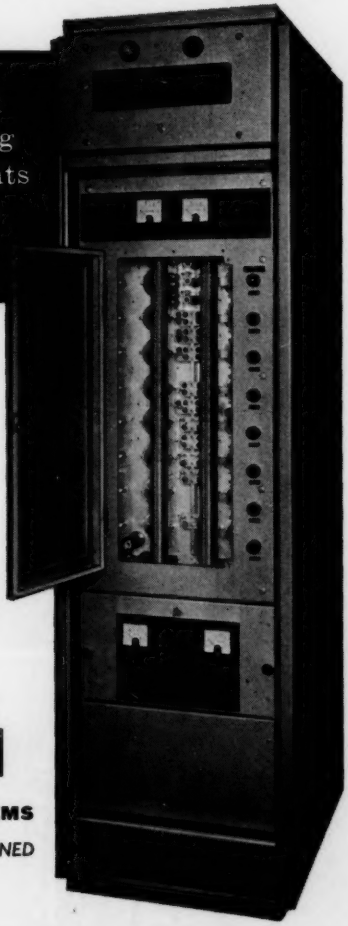

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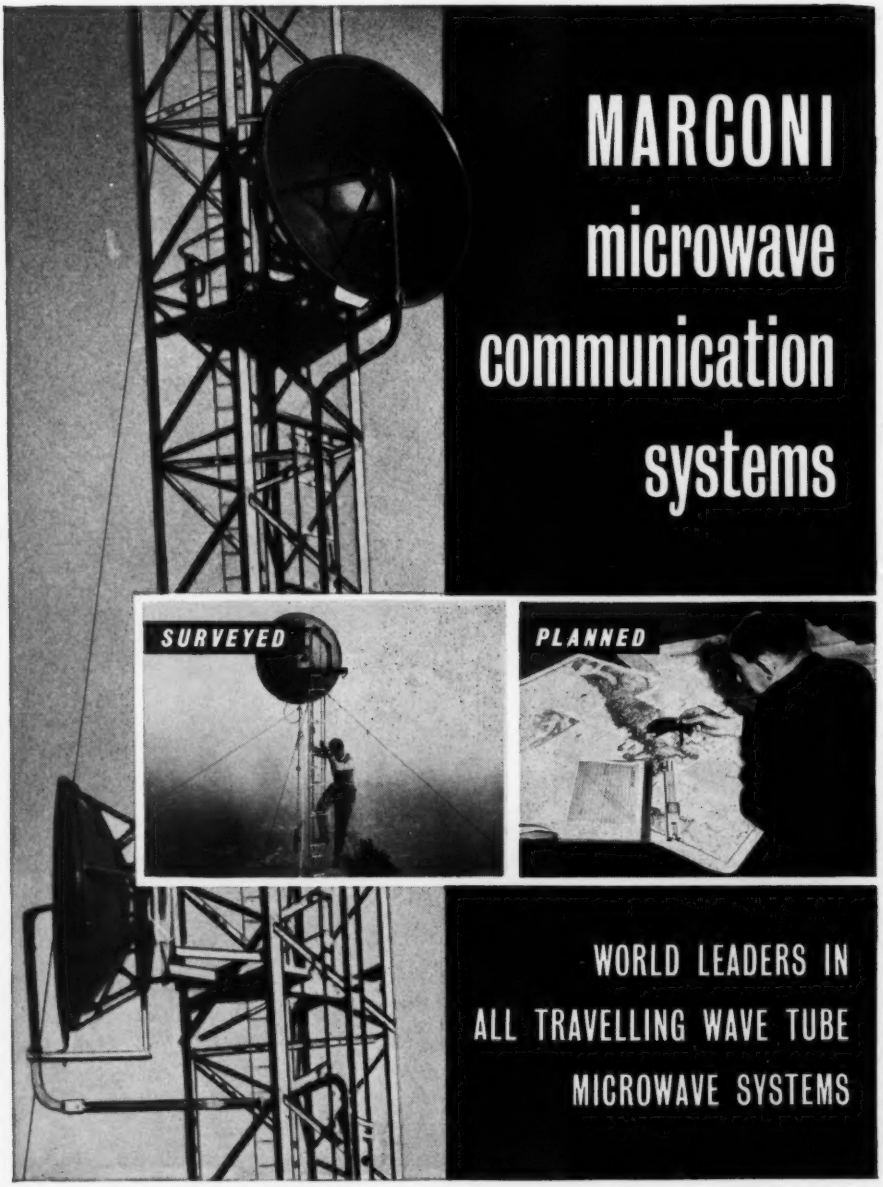
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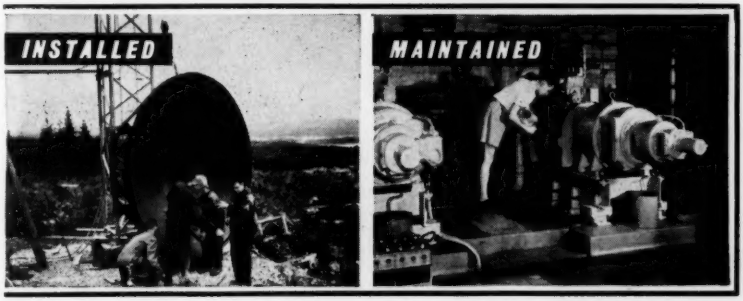

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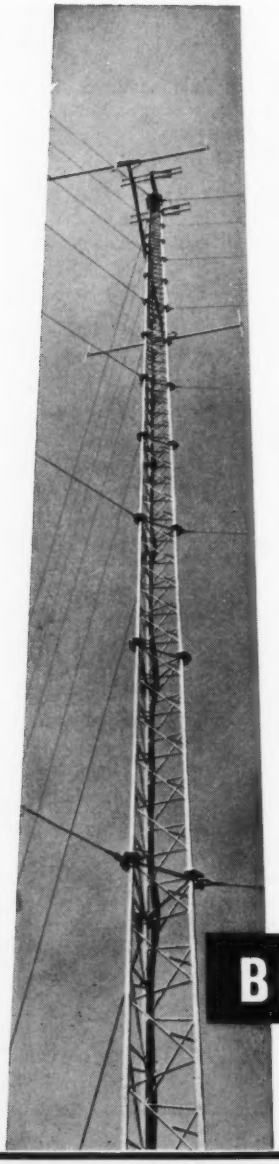

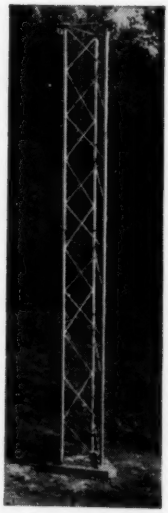

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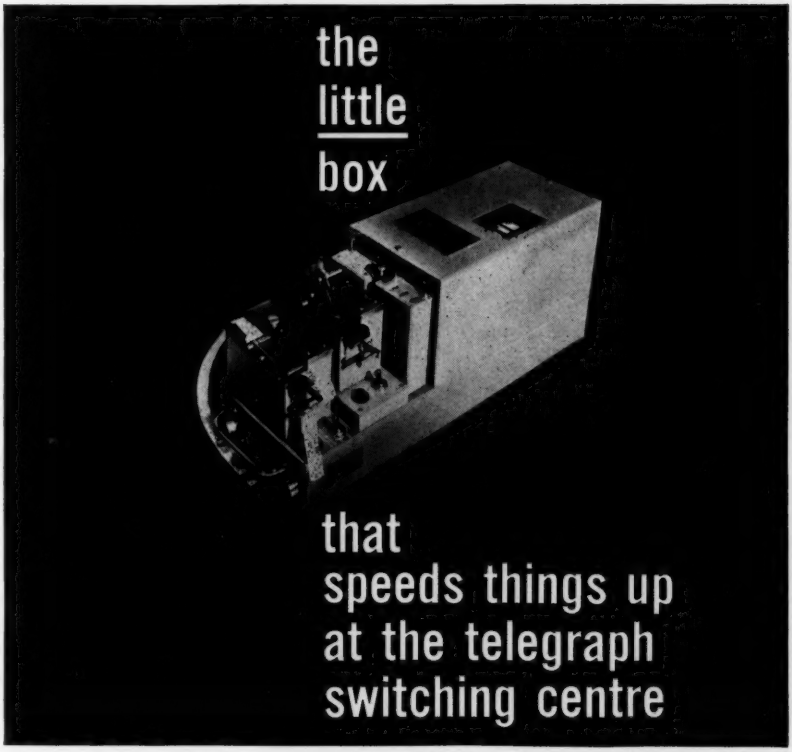

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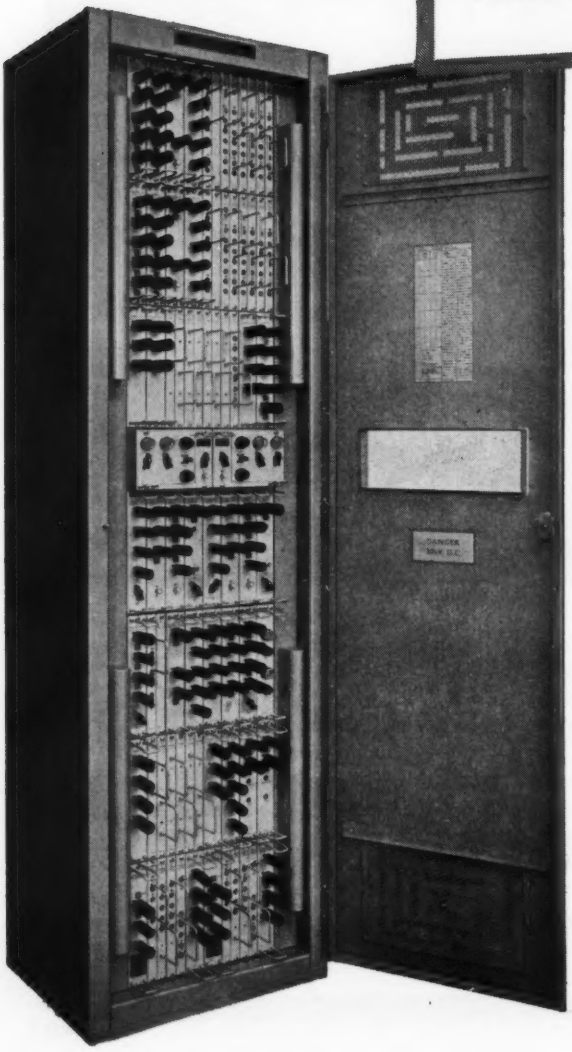

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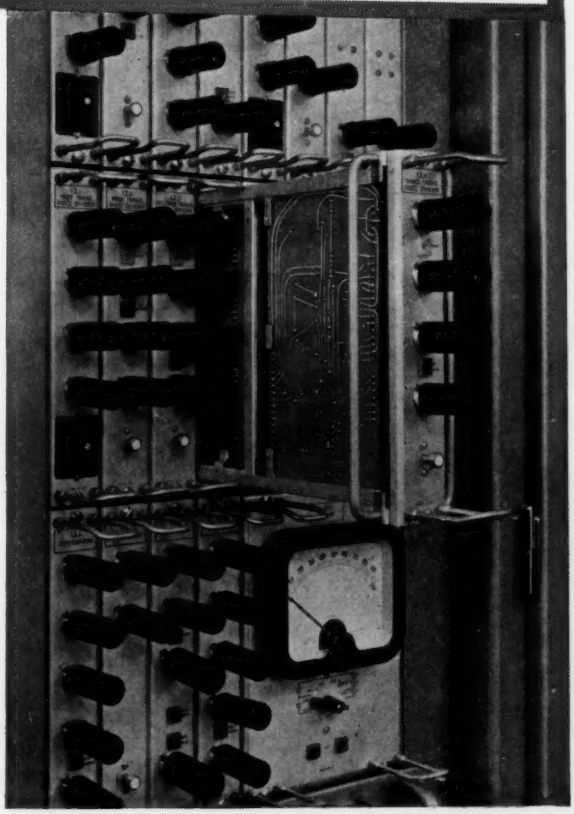

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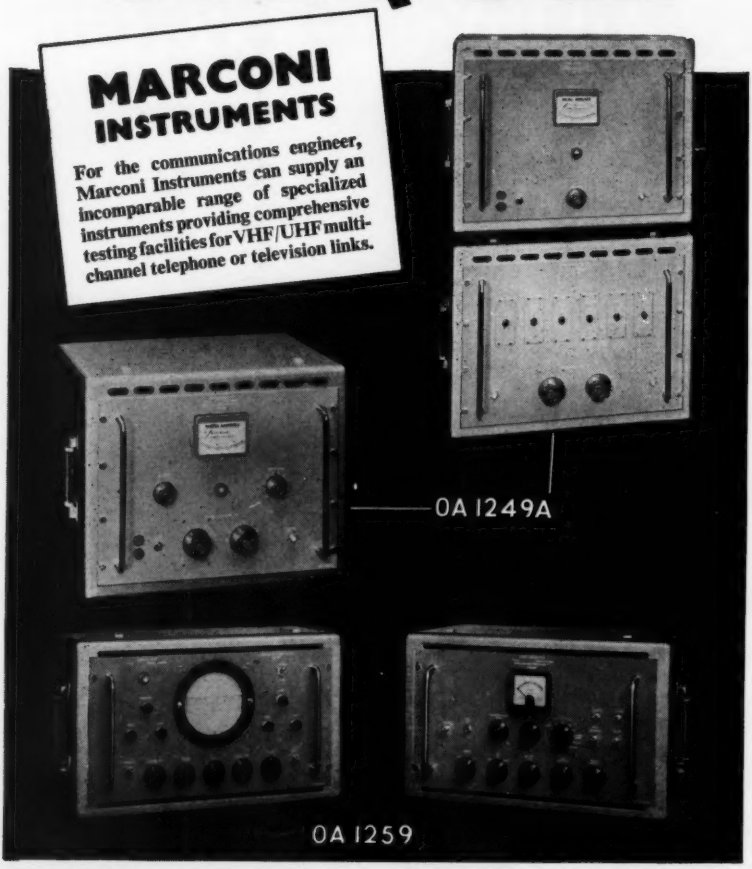
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